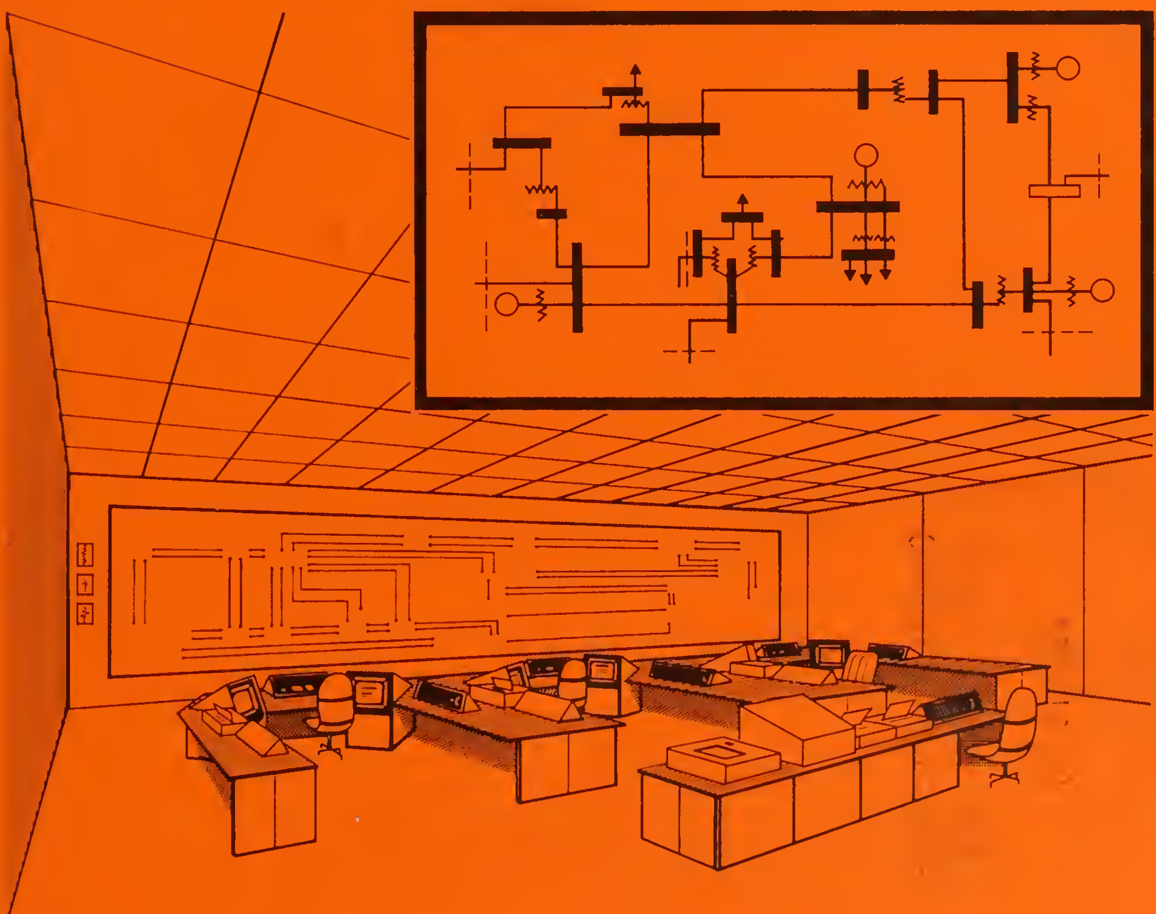
POWER SYSTEM COMMUNICATIONS:

SUPERVISORY CONTROL AND ENERGY MANAGEMENT SYSTEMS



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FOREWORD

REA Bulletin 66-10, "Power System Communications: Supervisory Control and Energy Management Systems," is part of the series of REA bulletins dedicated to power systems communications and control systems. This publication is the first of its kind to specifically deal with rural electric cooperatives' design and implementation requirements for supervisory control and energy management systems. The subject area of this bulletin includes control functions, operations, design considerations, hardware and software requirements, design criteria, system implementation, and costs.

The functional presentation of the material in this bulletin should be of significant value to all cooperative engineers and consulting firms and particularly helpful to engineers beginning their careers in power systems control and energy management.

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SUPERVISORY CONTROL

AND

ENERGY MANAGEMENT SYSTEMS

POWER SUPPLY AND ENGINEERING STANDARDS DIVISION
RURAL ELECTRIFICATION ADMINISTRATION
U.S. DEPARTMENT OF AGRICULTURE

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I. GENERAL

A. Introduction

This bulletin provides a planning and design guide for electric system borrower energy monitoring and control systems. The planning and engineering procedures are based on the classical systems engineering approach which has proven to be very effective in planning large, high technology projects.

Four basic categories of real-time control systems are commonly used by REA electric borrowers. They include:

- Supervisory Control and Data Acquisition (SCADA)
- SCADA with Automatic Generation Control
- Energy Management Systems
- In-Plant or Direct Digital Control Systems

Supervisory Control and Data Acquisition (SCADA) systems are intended primarily for periodic data acquisition from substations and generating stations and for remote control of equipment at these stations. They are occasionally expanded to also include automatic generation control. Other functions common to SCADA systems include alarm generation, log and report generation and electronic tagging. In some situations SCADA systems are also used to acquire, store and selectively forward data from a regional control center to a central system control center.

Energy Management or Energy Control Systems are an outgrowth of SCADA systems and usually include most SCADA system functions although supervisory control is occasionally omitted. Energy Management and Energy Control Systems are characterized by incorporating a broader and more complex set of functions than is found in the typical SCADA system. These functions may include a wide range of generation, transmission and system security applications requiring more extensive data acquisition and computing facilities.

In-plant or Direct Digital Control (DDC) systems are typified by those commonly found in generating stations for unit monitoring, start-up, shutdown, and for unit allocation. Functions of these systems vary considerably between fossil fuel, nuclear and hydro generating plants.

Many system configurations are possible for utility monitoring and control systems. The configuration best suited to a specific case is largely dependent on the size and geographical arrangement of the system to be monitored and controlled as well as established operating philosophy of the power system. The smaller systems are almost always centralized with a single control center. Larger systems are occasionally configured in a decentralized manner with several regional data collection points and a central coordination center.

The system dispatcher, aided by a modern computer control system, will be able to achieve the full benefits of interconnected operations. Timely participation in interchange transactions will ensure that resources are utilized optimally in pool operations with attendant economies in cost savings shared with other member companies. Billing data gathered automatically by the computer system will allow the dispatcher to audit the actual benefits and to discover any opportunities for additional economic benefits.

A computer system providing system monitoring, automatic alarming, and periodic logs, will require a minimum of manpower to provide service to the member cooperatives. The computer system will have the capability to expand as the power system grows placing only minimal additional demands on system dispatcher manpower.

Additional benefits will accrue from a complete system of data acquistion and control. System dispatchers will be able to monitor continuously all the important parameters in the generation and transmission system to maintain a high level of security and efficiency of operations. In case of emergencies, system dispatchers will be able to pinpoint the problem area, assess the extent of the disturbance, evaluate courses of action and take direct control actions in seconds. Control decisions will be made with confidence derived from current information of all affected parameters. A modern man/machine interface provides the system dispatcher with data displays organized for maximum comprehension in various levels of detail, and with a common control interface that further minimizes the possibility of error. Outage durations will be reduced and the improved service to customers will enhance public confidence in the Rural Electric Cooperatives.

B. Purpose

The design and implementation of a power control and energy management system is an undertaking of significant proportions. There is exposure to many disciplines and the potential for problems is substantial. As with all complex engineering tasks, the definition of requirements is one of the most important phases of the project. Design and implementation can proceed in an orderly manner only if based on a complete and clearly stated set of requirements. The purpose of this bulletin is to serve as an introduction to power control and energy management systems and to present certain design and application guidelines bearing on the overall implementation of the control center facility, hardware, and software design.

C. Scope

The engineering work required to place into operation a new control system consists of several distinct phases. This bulletin presents an overview of power control and energy management system functions, operations, design guidelines, project management, training and related activities.

D. Trends

Modern system control centers which have been placed in service since the start of the 1970's and also those which are in the process of implementation have many of the following features and functions:

- ° Heirarchial structures consisting of several levels of computer systems
- ° Dual real-time processors or multi-processors plus redundant peripherals
- ° High-speed digital telemetry and data-acquisition equipment
- ° System-wide instrumentation of electrical quantities and device status
- ° Color CRTs with graphics for interactive display
- ° Dynamic wallboard group display
- ° Automatic generation control
- ° Economic dispatch calculation

- Automatic voltage (VAR) control

- Supervisory control (breakers, capacitors, transformer taps, generating unit start-up and shutdown)

- Security monitoring

- State estimation

- On-line load flow

- Steady-state security analysis

- Optimum power flow

- Automatic system trouble anlaysis

- On-line abort-circuit calculation

- Emergency control-- automatic load shedding, generator shedding, line tripping

- Automatic circuit restoration

- Programmable remote terminals

There is no control system that has all of the functions just enumerated. This is to be expected. Operating problems and philosophies differ due to different networks, generation resources, and structures of operating responsibilities.

II. CONTROL FUNCTIONS, OPERATIONS, AND SUBSYSTEMS

A. Introduction

The terms Energy Control or Energy Management System are used in the same context as Supervisory Control and Data Acquisition System. The functions of these systems are virtually synonymous, or can be made such that they are indistinguishable from one and another.

Throughout our electric cooperatives in the United States today, the traditional dispatchers offices are giving way to modern computerized control centers. This change from the old to the new is not merely one of modernization of dispatching or supervisory control to a more comprehensive and integrated approach to monitoring and controlling a power system.

The control of the operating process can be divided broadly into two groups: those that operate automatically, and those that depend on the action of an operator. Relay initiation control to isolate components that malfunction fall into the automatic category.

With the development of telemetering and digital computers, centralized control functions became possible. Among the first parameters selected for control were the load frequency and the level of power exchange with neighboring systems. In the case of load frequency the total load of all generating units of the system was controlled to keep the system frequency within specified limits. The controlling of the level of power exchange with neighbors led to economic dispatch whereby power is scheduled to minimize fuel costs. These are some of the centralized control functions where information from many locations in the system are needed in the decision or control process.

Current state-of-the-art demands that system operators be involved in the decision making process and similarly for control centers to exist, real-time information must be received from the power system. The data acquisition system performs this function and the man/machine interface displays the information to the operator. The overall goal of the man/machine interface, through proper design of a Supervisory Control System, is to present the minimum amount of information in the most understandable format for the most rapid decision to be made.

B. Power System Control

A control system provides a means for remotely supervising the operation of equipment and devices. In an electric power system, supervision is conducted from a central location or dispatch center. The supervised equipment and devices are located remotely in substations and switchyards, and in unattended hydro-electric plants, diesel-electric plants, and gas-turbine electric plants.

The term "supervisory control" usually implies a method of remote control and indication, utilizing communications channels such as microwave radio, VHF radio, powerline carrier or telephone wirelines.

A control system can provide any or all of the following functions:

- Control
- Status Indication
- Alarms
- Telemetering

Control can be applied to circuit breakers, transformer tap changers, capacitor banks, reactors, unattended power plants and other apparatus. Status Indication provides information as to the present status of circuit breakers, tap changers, switches, equipment and other apparatus. Alarms signal the change of status of circuit breakers, switches, equipment and other apparatus. Alarms also signal equipment failure, unauthorized entry, and extreme excursions in temperature, voltage and other quantities. Telemetering provides information on a continuous basis or on demand, any measurable quantity (measurand) including but not limited to, voltage, amperes, watts, vars, kilowatt hours, phase angle and power factor.

The techniques employed in supervisory control systems have undergone rapid changes in the last decade and are still undergoing innovations. Mechanical relay-type systems are rapidly being supplanted by solid-state systems. The earlier versions of solid-state systems employing discrete semiconductors have given way to integrated-circuit-oriented systems. The quiescent mode of operation is being superseded by the continuous-scan mode. Small digital computers, called central processor units (CPUs) are being incorporated into supervisory control systems and are markedly changing conventional supervisory concepts. These mini-computers have made possible what is known as computer oriented real-time Supervisory Control and Data Acquisition Systems, abbreviated SCADA.

The goal of system control center design is the implementation of security control.

Security control requires the proper integration of both automatic and manual control functions, i.e., a total systems approach with the human operator being an integral part of the control system design. Security control requires that all conditions of operation be recognized and that control decisions by the main computer system must be made not only when the power system is operating normally, but also when it is operating under abnormal conditions.

The power system may be assumed as being operated under two sets of constraints, load constraints and operating constraints.

The load constraints impose the requirement that load demands must be met by the system. The operating constraints impose maximum or minimum operating limits on system variables and are associated with both steady-state and stability limitations. Mathematically, the load constraints can be expressed in the form of the familiar load flow equations. The operating constraints may be expressed in the form of inequalities, such as on equipment loadings, bus voltage, phase angle differences, generator real and reactive powers, etc.

The conditions of operation can then be categorized into three operating states--normal (or preventive), emergency, and restorative.

A system is in the normal state when the load and operating constraints are satisfied. It is reasonable to assume that in the normal state the power system is in a quasi steady-state condition. For any given time, the intersection of the load constraints and the operating constraints defines the space of all feasible normal operating states. The power system may be operated anywhere in this space.

A system is in the emergency state when the operating constraints are not completely satisfied. Two types of emergencies may be noted. One is when only steady-state operating constraints are being violated, e.g., an equipment loading limit is exceeded or the voltage at a bus is below a desired level The other is when a stability operating constraint is violated and as a result of which the system cannot maintain stability. The first type of emergency may be called "steady-state emergency" and the second type, "dynamic emergency". For the moment, however, we shall not distinguish between the two types of emergency.

A system is in the restorative state when the load constraints are not completely satisfied. This means a condition of either a partial or a total system shutdown.

In case of a partial shutdown the reduced system may be in an emergency state. This is the start of a cascading situation, and if uncorrected, would lend to a further deterioration of the system.

The concept of three operating states breaks up the complex overall operating problem into three operating sub-problems with different control objectives. Of primary interest and of major impact on the design of system control centers is the control done in the normal state. It is basically the development and implementation of functions in this area that represent the state-of-the-art in system control centers. Emergency and restorative controls are needed for a complete security control system, but so far their implementation at control centers has been very limited in scope and in ingenuity.

The effectiveness of security control depends heavily on the control done during the normal operating state. If a system could be controlled so that it remains normal 100% of the time, then all the load constraints would be met without any problem and there would exist the maximum opportunity for realizing the full economic benefits of sound operating. The objective of security control may therefore be restated as follows: to keep the power system operating in the normal operating state, i.e., to prevent or to minimize the departures from normal state into either the emergency or the restorative state. To realize an effective strategy for carrying out this objective, let us look more closely into the concept of system security.

1. The Concept of System Security

System security may be considered as the ability of a power system in normal operation to undergo a disturbance without getting into an emergency condition.

The system is then said to be "secure". On the other hand, a normal operating system would be "insecure" if there were a disturbance which could bring about an emergency operating condition. In practice, system security is determined with reference to an arbitrary subset of the complete disturbance set. This subset is called the "next-contingency" set. The choice of the composition of the next-contingency set is dictated by the probability of occurence of the contingency within the next short period

of time (in the order of minutes) and the consequences to the system should the contingency occur.

In most power systems the next-contingency set includes, as a minimum, the following types of disturbances:

- Any circuit out
- Any generating unit out
- Any phase-to-phase or 3-phase short circuit

Other types of disturbances may be added. The more disturbances included in the next contingency set the more stringent the system security requirements become.

For a given next contingency set, the set of all normal operating states may be partitioned into two disjoint subsets--secure and insecure. That is, a normal operating system is either secure or insecure. For security control to accomplish its objectives of preventing or minimizing departutres from the normal state it is highly desirable to be able to identify, firstly, whether the system is normal or not, and secondly, if normal, whether the system is insecure or not, and thirdly, if insecure, what corrective action may be recommended to make the system secure.

2. Characteristics of Security Control

The previously stated objective of system control center design is the implementation of security control in the broad sense of integrating all required automatic and manual functions for all conditions of operation. From this prospective the general patterns can be seen in which system control centers have been developing in the recent years.

The necessity for integration has brought together the previously separately implemented function of generation control and transmission control into one system. For geographically small power systems the integration is carried out in the system control center. For large systems or systems with existing regional or area control centers this integration is accomplished by linking the centers at various levels into a computer heirarchy.

The new requirement of security monitoring alone has necessitated the collection of a large volume of real-time system data every few seconds and has brought about the use of filtering and state estimation techniques.

In addition, the integration of automatic and manual functions is being manifested in the form of advanced display devices and techniques. The CRT with limited graphics has become the universal man/machine interface for system control centers.

3. Functions of a Control Center

In this section certain of the real-time functions that are generally of widespread concern to system operation are summarized.

a. Automatic Generation Control (AGC)

The function of Automatic Generation Control (AGC) is to determine the generation required to meet the actual system load and to allocate this generation among the regulating units, coordinating the requirements of regulation with the desired base operating point of each unit. The last part of this definition identifies an important interface between AGC and some other function which calculated the desired base points or settings. Traditionally,the base settings are determined by the economic dispatch function. But in our concept of security control this need not always be the case. During certain operating conditions, other functions such as security analysis or emergency control could establish the desired base operating points.

The basic AGC algorithms, i.e., the calculation of area control error and the assignment of regulation to each unit recognizing the desired base points, are well known. To apply these algorithms in a system control center requires the addition of modules which in effect interface with the real-time environment. These modules should initialize the AGC function, coordinate all information from other programs which affect AGC, prepare and hand off to the data acquisition subsystem the signals to be sent to the plants, and communicate with the display subsystem.

The use of plant computers communicating with the system control center offers flexibility for carrying out the AGC function. The AGC software at the system control center sends desired signals for each regulating unit to the plant computers.

The plant computers act as local closed-loop controllers for each unit. The control algorithms at the plant computers recognize the individual rate of response of each unit. Over the same data links the plant computers report to the system control center every second the control status of each unit and its short-term raise and lower capability. This information is used by the AGC algorithm such that the desired mw requested is within the dynamic capability of the unit. The computer-to-computer link also handles special requests by a unit operator to place a unit off or on regulation or to change a unit's operating limits.

b. Economic Dispatch Calculation (EDC)

Economic Dispatch Calculation is performed every few minutes using the set of coordination equations which requires that the incremental cost of delivered power from each generating unit to an arbitrary reference point to be the same for each unit. The incremental cost of delivered power for a given point from a generating unit is equal to the incremental cost of generated power multiplied by a penalty factor. Traditionally, the penalty factors are calculated using transmission loss B-constants.

In present day control centers, B-constants are usually calculated off-line and are updated very frequently. There is an economic advantage to be gained in updating B-constants on-line especially in these times of high fuel costs.

In centers where a real-time load flow is required for other reasons, it would be possible to calculate the penalty factors on-line by adding a real power optimization routine thus obtaining an optimum power flow. So, every time there is a network change or when the system load has changed significantly in magnitude or in relative distribution between areas, the optimum power flow runs automatically and a new set of penalty factors is passed on to the EDC. The penalty factor calculation requires on the order of 35 to 45 seconds to complete. This is the total response time and includes the network configuration update, 3 to 4 fast decoupled load flows, Jacobian calculation at the optimum solution point, calculation and transfer of new penalty factors to the data base.

Although EDC should be made only for those units which are regulating, it is desirable to make another calculation including all the other units on local control. This second-pass EDC is made everytime the regular EDC is run. The results of the second-pass EDC are displayed to the operator so that he may manually direct the units on local control to be moved closer to their optimum generating points. Considerable additional economy may be realized this way.

c. Supervisory Control

Supervisory control is not a new operating function. Its integration into a system control is new. Since supervisory control is a manual function it is exercised via the man/machine interface of the display subsystem. The integration of supervisory control of circuit breakers is not always straightforward.

The common approach has been to retain this function at the lower level and merely report the breaker status to the central or higher level. Such a structure will need reexamination of the interfaces in the event that there would be a requirement for breaker control from the higher level. An example of this would be some form of emergency control such as load-shedding or system splitting.

When there is a need, the control center may also perform supervisory control of voltage regulating devices (SVC) such as tap changers, capacitors, and generator voltage regulators.

d. Automatic Voltage/Var Control (AVC)

The automatic control of system voltage and of var allocation is not yet in wide use even by those companies who feel they need it, primarily due to the absence of an efficient on-line optimization algorithm.

The AVC regulates the voltage profile and also minimizes losses due to reactive power flow. The control variables are generator reactive powers, transformer taps, shunt capacitors, and shunt reactors. The control is a two-step orientation. Voltages and var flows are checked periodically and when there is any deviation beyond certain tolerances the voltage profile control calculation is initiated. At less frequent intervals the minimum loss calculation and control is executed.

e. Security Monitoring (SM)

Security Monitoring (SM) is the on-line identification and the display of the actual operating conditions of the power system. This one function has made the difference between the traditional dispatch center and the modern system control center. SM requires a systemwide instrumentation on a greater scale and variety than that required by a center without SM. The types of measurements include: MW and MVAR flows, branch currents, bus voltages bus MW and MVAR injections, frequencies, energy readings, circuit breaker status or operation counts, manual switch positions, protective relaying operations, transformer tap positions, and miscellaneous substation status and alarms.

The SM function, in general, checks the analog values against limits basically to determine whether the system is close to, or at, the emergency state. The limit-checking also allows some kind of data validation and the rejection of incongruous data. Limit-checking is done as often as the data is brought in which is usually in the order of every one to a few seconds.

The display required for SM entails the use of CRTs and a large number of display formats. The dynamic wall display is also used for SM. Part of the SM function is the on-line determination of the network topology. In most cases, it is sufficient to determine the network configuration. In centers where there is a direct responsibility for transmission, switching and safety is a paramount factor. The SM function should include an identification of the electrical status (energized or de-energized) or every physically isolatable segment.

f. Static State Estimation (SE)

State Estimation (SE) may be defined as a mathematical procedure for calculating, from a set of system measurements, a "best" estimate of the vector of bus voltage magnitudes and phase angles of the network.

The measurement set is understood to contain an adequate degree and spread of redundancy to allow the statistical correlation and correction of the measurements, detect and preferably identify bad data,

and yield calculated values for non-telemetered quantities.

Although there are just a few control centers with SE in operational use, the value of operation of this function is becoming more widely acknowledged. Recent specifications for control centers include SE as part of the software requirements. As presently practiced, SE is used for the following purposes:

- Bad data identification
- Calculation of non-telemetered or missing data
- Provide inputs to security monitoring function
- Provide vector of bus injections for an on-line load flow, security analysis, and bus load forecasting

g. <u>On-line Load Flow (OLF)</u>

An on-line load flow (OLF) is one which is used for real-time functions such as security monitoring, security analysis, penalty factor calculation, and may also be used for study purposes. OLF makes use of real-time data.

The OLF requires a vector of bus injections. In the general case, the bus injections are calculated from statistical data obtained on-line and some off-line historical information.

The bus injections may also be obtained from the results of a state estimation program. These injections may be used as they are or normalized to produce a set of load distribution factors. These distribution factors may be projected to a future time for predictive purposes.

The on-line load flow is a necessary function for system control centers. It should not be interpreted, however, as supplanting state estimation. As we have seen, these two functions serve different needs. Since the on-line load flow uses bus injections which are statistical in origin, the ultimate OLF should give results with some kind of statistical interpretation, i.e., an stochastic load flow. We are not yet there with the present state-of-the-art. However, the basic formulation of the OLF for penalty factor calculation, for establishing the base case of security analysis, and as an alternative method for performing contingency evaluation is of current value at system control centers.

h. <u>Steady-State Security Analysis (SA)</u>

The first function of security analysis (SA) is to determine whether the normal system is secure or insecure. The second function is to determine what corrective action strategy would be taken when the system is insecure.

The first function is commonly known as contingency evaluation since by definition, the security of a system is determined with reference to a set of next-contingencies. In present state-of-the-art, only steady-state contingency evaluation is done at system control centers. That is, the emergency condition that is to be avoided is overloading of equipment or poor bus voltages.

Security analysis as presently modeled requires an up-to-date equivalent of the external interconnection. So far, the only equivalent available and used at control centers have been traditional equivalents which have several recognized shortcomings. There is now a revised interest in equivalents for security analysis. Two basic types are emerging: topological and non-topological. Topological equivalents, like the traditional equivalent, are derived from prior knowledge of the detailed external system. Non-topological equivalents require no physical network information but are derived from real-time measurements via stochastic approximation techniques. Work on non-topological equivalents is continuing and initial results have been reported in the literature.

As discussed previously, the space of feasible normal states may be partitioned into secure and insecure regions. This, of course, is a dynamic situation. As the system generation, load, and topology change, so does the space of normal states and so does the boundary between secure and insecure regions. In fact, either region could be a null subspace. Clearly, as system conditions change, the contingencies in the next-contingency set which yields insecure operating points also change. At times the system is very strong such that no contingency in the next contingency set can cause an emergency, the insecure region is null, and contingency evaluation is not required. At other times only certain contingencies need be evaluated.

Presently, we do not have any really satisfactory techniques for accomplishing security analysis. We are thus compelled to use a fixed list of contingencies, perhaps with some spare room for operator-specified contingencies. Since the security analysis routines could impose a large computational burden, in certain centers the next contingency list is pared down to a small number of items. This is not always possible. There could still be enough contingencies to cause loading problems of computer resources. Part of the problem is the requirement that security analysis be run periodically, 24 hours a day. An alternative approach would be to use the Security Monitoring function to determine whether or not there is a need for SA. This could be based on arbitrary levels of line loadings.

C. The Computer Subsystem

The Computer Subsystem is the primary tool in the control center. It is the heart of the operation - controlling generation and transmission, gathering and analyzing data, generating logs and updating displays. All these real-time operations are based on operator inputs and data acquired utilizing logic programmed into the computer. The initial capability and ultimate expanded capability of the computer subsystem is a major factor determining the responsiveness of the control system and the ultimate workload of the control center.

By acquainting the reader with the computer hardware and system software, the advantages and disadvantages of various options, and functions and features required in the unique environment of real-time control center, it is hoped to help the prospective control center purchaser better understand the design guidelines and requirements of section III.

1. Overview of Computer

The basic hardware elements of the computer subsystem include the Central Processing Unit (CPU), the Input/Output Processor (IOP), Main Memory, and Peripherals. The CPU is the master controller of the computer, and it performs the arithmetic operations and makes the logical decisions. The Main Memory is the storage location for the data and the programs that use the data. The IOP transmits data between the Main Memory and the Peripherals, while the Peripherals convert the data into an output format for human intelligence, or input for computer

utilization. This basic hardware is one of the operating system's resources. The CPU under direction of the operating system will call application programs which in turn will maintain the data base and control the power system.

Computers are organized along two major architectural systems. In one case, the computer consists of a multiple number of busses. One bus for the CPU and other busses for each IOP. Attached to the IOP are the various Peripherals that are part of the computer subsystem. The busses are connected to Main Memory through multiports permitting the CPU and the IOPs to operate independently and simultaneously. In the second case, there is one bus that connects the CPU and all the IOPs to Main Memory. The Peripherals are attached to the IOP's. In this case, the access to memory by the CPU and the IOP's is done sequentially on a priority basis. This permits a common design for the element's interfaces to the single bus.

The advantage of one architectural system over the other is not inherent in the design. The sequential operation of the single bus system can overcome the possible advantage of the simultaneous operation of the multibus system by being much faster and simpler in design.

While most computer subsystems have the same basic elements, there is a difference in their capabilities and performance. The major factors contributing to performance are word size, maximum Main Memory, Peripherals, Bulk Memory, and I/O Bandwidth.

The range of computer word size is from 8 bits to 64 bits though the majority of computers in Electric Power Applications are 16, 24, and 32 bit words. Main Memory capabilities may range from 32 K words to about 1024 K words (where K equals 1024). The more usual values have been between 64 K words and 128 K words though the trend is upward.

Bulk Memory is composed of Peripherals that are attached to IOPs. Bulk Memory is critical to the performance of the computer subsystem and works in conjunction with Main Memory. Its size is measured in millions of bytes (Megabytes) where a byte is 8 bits. Bulk Memory capacity has usually been three to twelve million bytes but the trend is for greater capacities, as high as 40 to 80 million bytes.

The capability to transfer this large amount of data between Bulk Memory and Main Memory has put heavy demands on I/O processing throughout. I/O Bandwidth measures in kilobytes/second is the capability of the I/O to pass data between memory and its attached Peripheral. The usual values for I/O Bandwidth have been from 300 kilobytes to 1000 kilobytes per second but the computer subsystems for control centers are now exceeding 10,000 kilobytes per second.

2. The Central Processing Unit (CPU)

The CPU as its name implies is the center of the computer subsystem. It interprets instructions, compares values, accesses memory, and controls the flow of data in and out of I/O devices. Word size has a very important effect on the operation of the CPU. An instruction word usually consists of four parts: (1) an operation, (2) a Main Memory reference address, (3) a register address, and (4) modifiers. A 16 bit word may use 8 bits for address, 4 bits for operation, and 4 bits for a modifier such as index, indirect address and displacement. The register address is predefined and therefore it is not needed. A 24 bit word may use 14 bits for address, 6 bits for operation, 3 bits for register address and indexing, and one for modifier. A 32 bit word may have 17 bits for address, 7 bits for operation, 4 bits for register address, 3 for index register, and one for modifier.

The maximum amount of Main Memory that can be directly addressed is limited to the reference address bits in the instruction word. Thus 8 bits can directly address up to 256 words, 14 bits can directly address up to 16 K words and 17 bits can directly address up to 128 K words. By means of second instruction words, indirect addressing, indexing, using displacement registers, and extending bits, the maximum directly addressable Main Memory is usually between 64 K words to 256 K words.

A popular way to overcome address limitations imposed by the CPU is to employ memory mapping. Memory mapping may be accomplished by a number of different methods but most use part of the reference address of the instruction word to point to another register whose contents are appended to the reference address to permit addressing larger Main Memory. This also gives the added benefit of permitting programs to be segmented into different available areas of Main Memory and still appear contiguous to the operating system, thus permitting more efficient allotment of Main Memory.

Instruction set size can be determined from the number of operation bits, but by means of modifiers under special cases additional instructions may be inferred. The number of registers that are directly available to the CPU are also derived from the instruction word. Again, it is possible to extend this by such means as a modifier or use of a second word.

Instruction times for the simple direct operation such as load, store, add, etc. for computer subsystems commonly used in the ECC are 1.1 to 1.4 microseconds and somewhat independent of computer word size. However, the execution of programs containing these instructions may vary by more than 50% because the large word size machines may use fewer instructions. Also contributing to the faster execution times are such sophisticated techniques as look-ahead which permits more than one instruction in the operation cycle, register-to-register operation to eliminate access time to Main Memory, and the use of firmware or hardware is a typical requirement for systems providing unit dispatch and commitment and security functions.

Firmware which is literally burning in a program on an integrated circuit (IC) chip is a cross between hardware, where everything is done with components, and software, where the operation is done by a program. Firmware is not only used to perform specialized instructions, but to emulate the whole CPU. The use of firmware permits a reduction in manufacturing cost and an improvement in computer operation. The emulation of an existing CPU instruction set permits software that has been developed and proven to be used without modification. Thus, a computer whose CPU is emulated by means of firmware may be less expensive, operates faster and utilizes known and proven programs.

A CPU used in an ECC should have real-time operational features such as Real-Time Clocks, Multilevel Priority Interrupts, and Rapid Context Switching. The Real-Time Clocks permit the start of periodic function to occur at specific instants and be related to real-time. The use of Multilevel Priority Interrupts provides for rapid response to external events, with each interrupt identified and responding according to its priority. When responding to an interrupt initiated event, the CPU must use Rapid Context Switching to preserve the current envirorment and set up the new environment within a minimum time.

3. Use of Busses

The CPU works with other parts of the computer by means of busses that carry data as well as control and status information. The size and speed of the bus varies and obviously the faster the bus and the more information carried in parallel, the faster the overall operation of the computer. Busses connect the CPU to Main Memory and to the I/O processor and may be one byte or more wide.

There are two basic types of operations on the bus: asynchronous and synchronous. An asynchronous bus requires an answer back from the device or component addressed and thus usually is slower, but permits wider tolerance in cable lengths, placement of elements within the system, and response time. A synchronous bus may be faster, but each operation is run from a master clock which requires tight tolerances of cable and wire lengths, relatively less flexible arrangement of computer elements, and very exact response times because of possible problems in propagation and dispersion.

4. Main Memory

There are two types of Main Memory found in ECC computer subsystems. They are core memory and solid state memory. The core memory is the older type and has been in general use for more than 15 years, constantly being improved in its speed of operation and reliability. The cost of core memory over the years has steadily dropped. Solid state memory design concepts are not new, but only recently has solid state memory been found in computers for electric power applications.

Core Memory has one distinct advantage over solid state memory in that it is nonvolatile, it does not lose its information when power is turned off. Solid state memory is volatile, but this becomes less important with the various power backup methods that have evolved.

In other respects the specification for core memory and solid state memory are very similar. Access time for core memory ranges from 250 nanoseconds to 1200 nanoseconds, while solid state memory may not be much lower than 250 nsec. However, more importantly, core memory is performing as best as could be expected from its design; while solid state memory appears to be capable of much better performance. This includes access time, packing density, cost per bit, and reliability.

The need for greater packing density, lower cost, faster access time and greater reliability is due to the ever increasing demand put on Main Memory by the requirements of electric power applications.

Main Memory in a real-time computer subsystem should have a provision for error checking when information is read from memory. Two types of error checking are usually found; (1) single bit parity checking, and (2) multibit error checking and correction.

Parity checking is normally found in core and solid state memory but multibit error checking and correction is usually found only in solid state memory systems. Solid state memory can more readily add the extra bits needed for error checking and correction and it usually needs this enhancement for better reliability.

Since Main Memory cannot be indefinitely expanded to hold all the needed programs and data required by the ECC, Main Memory is divided into resident and overlay areas. Resident area holds those programs and their data which must be in Main Memory all the time because of their frequent use and importance to be completed within a very restrictive time frame. The overlay area is used by programs which are brought in from bulk memory when needed and thus more than one program may overlay the same Main Memory area. Main Memory size is usually determined by the requirements for resident programs and data, and the largest program needed in the overlay area.

Main Memory protection is required in real-time computer subsystems to permit the concurrent operation of the real-time programs with study and other support programs. Memory protection which may be controlled by hardware or software, or both, provides access protection of Main Memory and prevents inadvertent destruction of critical programs.

5. <u>I/O Equipment</u>

In order for the outside world to communicate with the computer subsystem, Input/Output Equipment is needed. Methods utilized include special processors called I/O processors, intelligent controllers, and direct I/O. Only the direct I/O is required to be under the constant control of the CPU. The I/O equipment is tied to the CPU and Main Memory by means of busses which send and receive data, control, and status information.

I/O processors are specialized processors that may be able to handle large numbers of input/output devices independently of the CPU. They usually consist of a number of channels, 8, 16, 32, in which there is a different device on each channel. All channels may be operated simultaneously. The only limitation is the bandwidth, or number of bytes being transferred by the I/O processors. To effectively increase the bandwidth more I/O processors may be added to the computer subsystem. Each processor may have its own access or port to Main Memory. In some designs the I/O processors do not have their own memory port, but share data with other busses to memory in which case the effective bandwidth is reduced by 10 to 20%.

The I/O processor can operate all its channels concurrently, sorting out which is to receive or send data. The I/O processor checks for any errors, determining where the data is to go and stopping and individual channel when the transfer is completed in that channel. It informs the CPU when its transfer is completed, sending the CPU the status of the channels performance.

Intelligence controllers have similar functions as the I/O processors, but are organized in a different manner. Each controller contains a microprocessor which is programmed in firmware to perform the input/output functions for that controller and its device. Thus, each intelligent controller must be programmed specially for its associated I/O equipment. The advantage of the intellingent controller is that no additional I/O hardware is needed than is used by the computer while an I/O processor must be designed and installed with the capabilities for its ultimate capacity. However, there is no effective means to increase the bandwidth of the I/O with intelligent controllers since they all operate on one bus and therefore the computer subsystem must have sufficient I/O bandwidth built into its original device for its ultimate application.

Direct I/O under control of the CPU is not normally used for the same functions that are used for the I/O processor or intellegent controller. The Direct I/O brings in or sends out the data through the CPU and therefore burdens the CPU with its operations. The Direct I/O is best suited for data that is limited to a few words or even to a few bits within a word. Its primary function is to enable the CPU to gain quick access to the outside world and to immediately interpret the information. Thus, inputs from

operator panels may be handled through the Direct I/O. Other possible functions are output to mapboards to show change in status and to recorders to update analog values. The enabling or disabling of a device for backup or failover may also be performed through the Direct I/O.

The I/O processor and the Intelligent controllers usually handle larger streams of data such as those from magnetic tape, card reader, and lineprinter peripherals. Bulk storage devices and CRT displays are also functions that use the I/O processors or intellegent controllers. Whenever the data stream is long compared to the overhead of the CPU for setting up the I/O processor or intelligent controller, it is advantageous to use this method. In cases such as data acquisition from remote terminals, the advantage of this method over Direct I/O is not as obvious. Since the length of the stream of data varies for different applications, both methods have been employed. It should be noted that the I/O processor and intelligent controllers always have the distinct advantage of doing all the functions of the Direct I/O without adding directly to the burden on the CPU.

6. <u>Bulk Memory</u>

One of the most important devices within the I/O equipment group is the Bulk Memory. Bulk Memory provides the permanent storage of all programs in Main Memory resident as well as the overlay area. Included in Bulk Memory storage is the data base, historical files, operating system, and temporary storage for overlay area programs.

Two major types of Bulk Memory devices are the Fixed Head Disc (FHD) and the Movable Head Disk (MHD). The FHD has one magnetic head per track with both read or write capability; while the MHD has one magnetic head per surface which is moved from track to track. The FHD can start to transfer data to or from the disk as soon as the segment or sector of the track reaches the head. The MHD must move the head to the track of interest and then wait for the sector to pass under the head.

FHD may have 8.5 millisec to 17 millisec average access time which is the wait time between requesting the data and start of transfer of data. Average access time is one-half a maximum access time and under many circumstances average access time can be reduced or eliminated by means of simple algorithm.

MHD's have average access time of 30 to 50 millisec which is the combination of the average time to move from one track to another and the average time for the sector to reach the head. The maximum access time is double the average access time and there is no simple algorithm to reduce the value to zero.

In addition, FHD may have write protect switches which prevent groups of magnetic heads from writing on the disk without interfering with their ability to read from these same tracks. MHD's do not usually have such features since the head moves over a large number of different tracks.

FHD usually ranges in size from less than one megabyte to about 20 megabytes while MHD's are sized from 2 megabytes to over 100 megabytes. Transfer rates of the two devices are relatively similar; the FHD ranges from 250 kbytes/sec to almost 1 megabyte/sec while the MHD is from 350 kbytes to 1.2 megabytes per second.

The cost of an FHD may be over 5 to 10 times more than an MHD, for comparable size of the Bulk Memory. Comparing the FHD to Main Memory the FHD is about 40 times less expensive per byte.

Because of the faster access time inherent in the FHD, the capability to protect certain tracks by means of write protect switches, and the higher cost per megabyte for a FHD, the choice of Bulk Memory has to be made according to the requirements of the ECC. Where high capacity is needed and slower access time can be tolerated, the lower cost MHD may be the better choice; but where faster access times are a necessity and the write protection required, then the FHD is preferable. In many ECC centers both are used, and their assignment is based on the requirements of the applications.

A third type of Bulk Memory is bulk core or solid state memory which is inexpensive memory but formatted to be similar to an FHD. The access time is always almost zero and the transfer rate can be as high as 1 to 4 megabytes/sec. Its cost is approximately 4 times less than Main Memory. The primary function of bulk core would be to work with the Main Memory overlay areas and to provide fast access and high transfer rates to large programs that would otherwise need undue amounts of resident Main Memory.

7. Long Term Storage

The CPU, Main Memory, I/O equipment, and Bulk Storage have been part of the real-time function of the computer subsystem. They are considered critical to the operation of the ECC. The long-term storage device while obviously important is not usually part of the real-time function. These devices include magnetic tape, card reader and punch, paper tape reader and punch. They provide the program source and object code storage as well as the data storage and may be used for system dumps of memory.

For systems found in energy control centers, magnetic tape and cards are usually used; while paper tape is used only for very special circumstances. Paper tape is much too slow a medium, usually transferring data at 300 to 1000 bytes per second. Given the size of systems at the ECC where Main Memory may be 128 K words and Bulk Memory over 10 megabytes, it can be seen that it could take hours to transfer programs and data in or out of the computer.

Magnetic tape specifications include the tape speed in inches per second (ips) and recording density in bytes per inch (bpi). Additional specifications include the recording method, which may be either non-return to zero (NRZI) or phase encoded (PE), and the recording format, which may be 7 track or 9 track. Most tape units operate at 37.5 ips, 45 ips or 75 ips with a recording density of 800 bpi or 1600 bpi, using NRZI with 800 bpi and PE with 1600 bpi. The almost universal format is IBM compatible 9 track in which 8 tracks are data and 1 track is parity. Tapes recorded at one speed may be read at another speed, but the magnetic tape unit must use the same recording density, recording method, and format.

Magnetic tape drive units use two methods for buffering the tape between reels. The lower speed units use mechanized arms to take up the slack between reels while higher speed units provide vacuum columns. The vacuum column is preferred over the mechanized arm because it reduces wear on the tape.

Changes to programs or to the data base is usually done via the card reader by cards that have been manually punched on a keypunch. Card readers transfer between 100 to 1500 cards per minute which can provide from 200 to 300 bytes/second. As can be readily seen, this is not a feasible procedure for reading whole programs into computer systems, but when a small number of cards are involved,

it provides a very reliable method. The most common procedure is to use the magnetic tape unit to load a computer with all its programs and data base. The update or modification information, once read into the computer via card reader, is merged with the information already in the computer and a new program or data base can be dumped onto magnetic tape for long-term storage.

8. Line Printer

Line printers provide programmers with hard copies of the programs and data stored in the computer. They are also used for output of large volume logs for historical purposes or records. They may have additional functions such as diagnostic printout or backup to on-line loggers. Normally the line printer is not considered part of the real-time functions of the ECC, but is very important to the update, modification and maintenance of the system.

Line printers are specified by the number of lines per minute printed which varies from 200 lines to 1200 lines per minute. Because of the heavy usage and the large volume of data printed, impact hammer type is preferred. However, at the lower speed,impact dot matrix printers may sometimes be used. The impact hammer type printer noise level is such that the manufacturers must encase the printer in a noise reduction enclosure. The noise level is reduced to below that of an office typewriter.

Printers normally have 64 character set, print up to 132 columns, take paper of various widths up to 19 inches, print 6 lines per inch, each line having 10 characters per inch, and provide a format tape to permit automatic page and line adjustment.

9. Programmer I/O Devices

Programmer I/O Device is usually either a KSR (Keyboard Send/Receiver) or a video terminal. It is used for programmer control and communication and gives a hard copy or visual display of all messages between programmer and computer. The Programmer I/O Device may be used for program checkout error messages and control of the computer during the maintenance period. It should not be used to dump extensive programs from the computer.

The KSR prints from 10 to 30 characters per second while the video terminal may be able to operate up to 10 times faster. When a hard copy device is attached to the video

terminal its output speed is limited by the printing speed of the hard copy device.

The KSR prints a 72 to 80 character line with 6 lines per inch. The video terminal is capable of displaying up to 24 lines, each line 72 to 80 characters wide. The character set commonly used by both is the USA standard code for Information Interchange (ASCII).

Every computer system must have an I/O Programmer Device in order to be able to start-up and be maintained. The choice of device varies widely and depends mostly on the preference of the user.

10. Physical/Environmental Requirements

a. Environment

The temperature and humidity requirements in the Control Center are most stringent for the computer subsystem. The computer subsystems usually found in Control Centers have upper temperature specifications of 32°C, though some may go as high as 41°C. The lower temperature boundary is very rarely important because the computer self-heat will maintain the minimum temperature. Beside the upper temperature boundary, many computer subsystems must have controlled temperature change which may be in the range of 12°C to 9°C per hour. Though the operating temperature range may be large, often the variation from the center temperature once established is less than the overall operating temperature range. The most vulnerable elements in the computer subsystem to temperature are the Main and Bulk Memories. Sometimes extra cooling for these devices may permit the rest of the system to operate at higher temperatures and over wider variations.

While it is the high temperatures that have an adverse effect on the computer subsystem it is the low humidity that can cause an unfavorable operating environment. High humidity, above 85% R.H., may cause some harmful effects to such media as card decks or magnetic tapes, but these are not normally part of the real-time operating system. As long as there is not precipitation of water vapor, high humidity is not essentially detrimental to the computer. However, low humidity below 20% R.H., may permit static discharges and cause erroneous operation within the Control Center.

The relative humidity should be kept between 25% and 80% to insure minimum unfavorable effect.

In order to control the temperature and humidity it is necessary that the Control Center have an adequate air conditioning system that is reliable. The computer subsystem usually requires from 15KVA to 40KVA of power depending on the size of the equipment. In turn, this may represent between 25% and 45% of the total power requirements for the Control Center. It can readily be seen that a failure within the air conditioning system may very well cause the ECC temperature to rise to a dangerous level due to the self heat of the equipment. While the total size of the air conditioning system may depend on many factors outside the sphere of the computer subsystem, such as local climate, building structure, location, etc., 100,000 to 500,000 BTU/hr. may be needed for the equipment at the ECC.

The primary input power to the computer subsystem can tolerate normal variations. The supply line voltage may vary as much as +10% while the line frequency may swing as much as 0.5 to 1.5 Hz. However, voltage transients or loss of power may be deleterious to the equipment. The CPU has usually a very sensitive power failure detector because it must be able to initiate an orderly shutdown in the computer subsystem. It detects loss of power within a few milliseconds in order to insure that the levels of the internal power supplies in the computer subsystem are capable of performing properly before shutdown is completed. Though when power is restored the computer will recover in an orderly manner, there is with every power failure a loss of information and control. The cycling on and off of the computer subsystem may also be a major contributor to equipment malfunctions. In addition,high frequency transients on the line that do not affect the power failure detector may affect the system performance by being transmitted into the logic and causing erroneous operation.

To overcome all these difficulties an Uninterruptable Power System (UPS) is recommended. The UPS may consist of an inverter, battery and battery charger, where the inverter converts the dc of the battery to the ac supply voltage for the equipment and the battery charger keeps the battery at proper operating level. The UPS may be backed up by the supply line or it may

be backed up by the line. The UPS obviously must be capable of supplying all the power needed for the equipment at the ECC. There are many configurations that can do this, varying from one UPS carrying the whole load to two or even three UPS sharing the load.

b. Availability

In order to achieve a high availability of the equipment at the ECC, not only must the environment and primary input be proper, but also the equipment configuration must be enhanced. Availability of hardware is calculated as follows:

$$\text{Availability} = \frac{\text{Runtime}}{\text{Runtime + Downtime}} \times 100$$

Where: Runtime is anytime during which the hardware is considered operating, and;

Downtime is anytime during which the hardware does not perform its required functions

The real-time components of the computer subsystem that perform the critical operation have an availability that is the product of the availability of each component. This includes the CPU, Main Memory, Bulk Memory and I/O equipment. The availability of such a group of elements may be from 99.3% to 99.7%. It should be noted that the calculated availability is based upon average values that may occur over a long period of time and thus there may be a wide variation for a short period. To achieve an availability of 99.8% the downtime should be less than 4 hours over a 2000 hours period (3 months, approximately). This may require a calculated value of availability of 99.8%. By means of redundant systems in which one computer subsystem is on-line and another is available as back up, the real-time group calculated availability can be enhanced to over 99.99%.

The parameters used for calculating the availability are based on the Mean-Time-Between-Failures (MTBF) and the Mean Time to Repair (MTTR) of each of the components of the computer subsystem. This data may be derived from a number of sources which include:

° Estimations based upon experience

- Comparison to previous similar equipment with known MTBF and MTTR

- Counting the number of active groups (transistors, integrated circuits) with a known MTBF

- Counting the number of each component part types (resistors, connectors, etc.) with a known MTBF

- Calculating the failure rate of each component part, by the stress analysis method according to U.S. Military procedure (MIL-HDBK-217 and MIL-STD-756).

In all these reliability prediction methods, only the hardware is taken into account. The overall control system availability is also influenced by the reliability of the software programs. However, software is not subject to the same probabilities of failure that are common to hardware. Software, once debugged and tested is not expected to fail with use. This is not to say that software is not without failures. In fact, many if not most, causes for the unavailability of the control system during startup are due to errors in the software.

Every control system has its own particular requirements which necessitates the development of some new software of the modification of previously written software. These new or modified software programs cannot be thoroughly tested and debugged under all circumstances until used in the actual system. A few problems should be expected during startup. These problems can be kept to a minimum if field proved software is used as a basis for creating the new or modified programs by a well experienced supplier. After startup the availability of control system should be found to be very satisfactory.

Beside increasing the availability, a redundant configuration that is symmetrical also supplies two other important functions. The backup system can be in use performing background function thus relieving the on-line system of some of its load. It should be remembered that the on-line system can do any function, including background.

Another important function of the symmetrical redundant system configuration is the checking out of any additions, modifications or deletions to the system. This may be done off-line on the back-up computer before they are incorporated into the operating system. This is true for both software as well as hardware. It gives a high degree of assurance that when the change is put on-line that it will perform satisfactorily.

11. System Software

Perhaps the least discussed element of the control system and the element least understood by the purchaser of control systems is the system software. Yet the responsiveness and ultimate capacity of the system are directly related to the efficiency of the operating system, and the cost of system maintenance and expansion is a function of the software support facilities provided. The function of the operating system is the efficient allocation of system resources in a multi-programming, real-time environment. The support provides the programming tools for hardware and software maintenance and system expansion.

It is desirable for the operating system to be specifically designed for real-time process control and monitoring. Very often operating systems labeled as real-time are in actuality general purpose or time-share executives that have been augmented for real-time operation. Because they were not designed specifically for real-time, such operating systems may be missing certain real-time features or can require excess overhead in performing real-time functions.

This portion of the bulletin is presented to acquaint the reader with the functions of real-time system software and the desirable features to be specified when purchasing a system. The importance of system software should not be underestimated. Undoubtedly, more development cost is behind the system software than any other element of any control center. The high cost of computer hardware is in part due to the "free" system software that comes with it.

a. Operating System

Within the multi-task, real-time environment, the operating system's function is the orderly and efficient allocation of central processor unit time,

main memory storage, auxiliary memory transfers, and input/output facilities. The operating system program fits within the computer's interrupt and priority structure.

While the efficiency and capability of the operating system as discussed in the following paragraphs is of obvious importance, the inclusion of unneeded functions can be costly. The operating system itself requires system resources - including typically 40K to 100K bytes of core and 5% to 25% of the CPU time. Thus, the goal is to maximize the operating system's performance while minimizing its own use of resources. Include the needed real-time features discussed below, but do not generate unnecessary functions into your system.

(1) <u>The Executive</u>

The executive is the operating system program responsible for scheduling CPU control and overall resource allocation.

The control flow is based on the priority structure. The calling of the executive through its interrupt signifies an impending change in system environment. Typically, the executive is called when a task (free standing program) relinquishes CPU control (e.g., task has completed, has initiated an I/O, has been aborted, etc.), when I/O is completed for which a task is waiting, or when a request for execution has been made. The executive selects the highest priority program requesting activation and for which required resources are available, allocates the required resources, and grants CPU control to the task.

Requests for execution are put into effect by (1) interrupts, (2) calls by other tasks, (3) calls by the periodic scheduler, and (4) computer operator command. When the executive activates a task, it first locates where the task is stored, allocates the required peripherals and files as defined by the task definition data, loads the task into main memory (assuming the task is not a resident program in memory), and grants it control. An important feature (often called look down or look behind) is the capability of the executive to

activate a lower priority task when any of the resources required by the highest priority task are being utilized elsewhere and thus temporarily not available.

Thus, on a priority basis, the executive controls allocation of the resource - CPU time. Similarly, during task activation, the executive also controls allocation of other resources - peripherals, bulk memory files, and main memory. Assignment of peripherals and bulk memory files may be static or dynamic and may be on a shared or non-sharable basis. However, most important is the allocation of main memory, for it has the greatest impact on the system workload capability.

Tasks are either main memory resident or bulk resident. The bulk resident tasks execute in the overlay area. The allocation of overlay is either dynamic or based on a fixed map. Dynamic allocation methods include:

- Software relocation based on modification of instruction addresses during the loading of the task

- Hardware relocation based on the hardware addition of a base register

- Memory mapping where a task is divided into minimum - size increments, usually called pages, and scattered about main memory wherever available space exists. Hardware registers keep track of the physical location of the pages

The features of a Real-Time operating system are:

- Task queuing based on software priority levels

- Preemption of low priority tasks for higher priority tasks

- Look behind

- Roll in/roll out

- Program non-interruptable status

- Automatic scheduling of periodic tasks
- Overlay of program segments
- Inter-task communications to allow sharing of data and logic
- Task requesting execution of another task with facility to pass parameters
- Real memory allocation providing for common data area, resident tasks, non-rollable tasks, and rollable tasks
- Foreground/background capability
- I/O control system with queuing mechanism for optimization of multiple I/O requests
- Threaded I/O queues per I/O channel allowing multiple requests for the same device to be held on priority basis
- Minimum latency algorithm for disk transfers
- Software interaction through task names, data names and operational labels rather than physical addresses
- Automated SYSGEN facilities
- System performance monitoring

In each dynamic allocation case, the executive searches main memory for available space. The key feature in either the dynamic or the fixed case is roll in/roll out (also called task checkpointing)- the capability to temporarily transfer an active lower priority task to bulk memory (to a roll-out area) when a higher priority task requires execution and sufficient unused space is not available.

Which is preferable - fixed map or one of the dynamic methods? Today, most large control centers are being installed with dynamic allocation. Fixed map is being employed mainly on small systems. The fixed map must be initially laid out with the ultimate system in mind. Such consideration

minimizes the programmer effort to map each new task added as the system grows. Dynamic methods eliminate the need to map the overlay. Of course, the most important consideration is efficiency; that is, minimum bulk traffic, minimum bulk wait, minimum CPU overhead, and as a result maximum ultimate capacity. At first glance, one might select the fixed map, which can be tuned to improve performance, as the most efficient. However, the task execution requirements in large systems are very dynamic. Thus, tuning that is optimal for one period of activity may not be optimal for the next period. Dynamic methods are created for changing environments and could potentially be more efficient. However, to date, no general method is by definition superior to another. Analysis of the specific approach and features, performance of benchmarks modeling the expected environment, and measurements from existing similar installations can all be used to help anticipate the performance of a given memory-allocation technique for a given planned control system.

A multi-task, real-time environment also necessitates inter-task communication facilities. Typical methods include the passing of parameters when one task calls another and the setting of indicator bits called flags. A common, global data base not only contains system data, but can also be used as an inter-task mailbox. Access to common data should be symbolic and not require the task's knowledge of a specific physical address. Such facilities become even more critical in multiple processor configurations.

(2) Periodic Scheduler

The periodic scheduler works in conjunction with the executive to automatically activate tasks based on time of day or elapsed time. While the periodic scheduler may be provided by the computer supplier, it is often an enhancement created by the system vendor. (Note 1) The user places a periodic task on the periodic queue and defines its start time and execution interval. Programs may be periodic or single shot. The periodic scheduler is assigned to an external interrupt driven by a real-time clock. Each time

the interrupt is triggered the periodic scheduler checks the periodic queue and places the appropriate tasks on the executive's queue. Resolution of a few milliseconds should be provided with intervals ranging from one second to 24 hours. Scheduler maintenance facilities should include capability to activate, deactivate, add, delete, and change parameters of periodic tasks.

Note 1: The system supplier usually supplies the computer as an element of his offering. The computer supplier, who supplies the computer to the system supplier, often may be a different company or a different group within the same company as the system supplier.

(3) Input/Output Processing

Input/output is accomplished either by direct I/O or by an I/O processing program. The facilities of the I/O processor are used in all cases except if a situation exists where the I/O transfer cannot afford the overhead of the I/O processor. Thus, direct I/O may be more typically used for infrequent and short transfers.

I/O processing involves both the general I/O processor and device - oriented I/O servers. The I/O server drives the device controller through which data is sent and received between main memory and the device. Server features should include priority I/O buffering, performance of error checking, and initiation of retries. The general I/O processor should be a device independent - operational labels used rather than devices names or addresses. Processor features should include I/O queuing with priority execution, format control, and code conversion.

Another desirable I/O feature is called "spooling". Spooling is the bulk buffering of I/O to and from a peripheral device, usually a low speed device such as a card reader or a line printer. Bulk buffering permits a task to read or write at a high rate to a disc rather than a low rate to a card reader or line printer. Also when the transfer is made to or from the low speed device, it is made at the maximum speed of the device rather than at the intervals at which the task is performing reads and writes.

(4) File Management

File management software maintains the tape and disc storage of programs and data and the directories defining such storage. Routines should be provided to allow creation and deletion of files and sequential and random file access.

These facilities also allow programs to request data values or tables or to call programs by name without having to know specific addresses. Data for energy control applications may be stored in tables rather than records and files. Tables allow the data base to be represented closer to the way the user understands and organizes his data, allowing for easier comprehension and expansion by the user. In this case file facilities provided by the computer supplier can be adapted by the system supplier to automate program and data storage, access, and modification. System supplier provided data base generation programs (described later in this section) should be designed to work with file management software so that a program's reference to data by name is automatically translated to a file name, offset into the file, and number of bytes required.

(5) System Generation (SYSGEN)

SYSGEN software permits the tailoring of the software system to reflect the hardware and software requirements of the user. Facilities provide for the selection of operating system features, definition of directories, files, and libraries, assignment of interrupts and devices, and establishment of resource parameters such as the amount of main memory.

Full sysgen, short sysgen, and reload facilities should be provided. Full sysgen is the initial SYSGEN performed by the system supplier. Short sysgen facilities, which are of particular importance to the user, allow rapid modification of the system using the previously generated system as a base. Such modifications would include the addition of a peripheral or the expansion of a file size. Short sysgen facilities are aimed at minimizing user effort and computer down-time. Finally, reload is the reactivation of the system

using the system image stored on bulk. Reload is an integral part of automatic start-up and fail-over described later in this section.

(6) Software Accounting

A software accounting program monitors system load. Accounting software is often a system supplier addition. It allows forecasting the effect of system expansion and analysis of ways to reduce CPU overhead and I/O wait time. Typical data measured and displayed includes CPU idle time, number of roll outs, number and average lengths of I/O requests, and average and peak load on the system task queue. This level of accounting activity produces negligible CPU overhead. The software facilities described in the above paragraphs are the major elements of the operating system and related software.

b. Support Software

The support software provides facilities to maintain and expand the system. Facilities for the addition, modification and deletion of application programs are typically created by the computer supplier and provided through a background monitor package. Capability to update the data base and CRT displays is provided by the system supplier through generation programs that, depending on the supplier, may be either foreground or background programs.

(1) Foreground/Background

Background is by definition either the lowest priority level in the system of a limited class of programs and is interruptable and rollable by higher priority tasks. Background programs are associated with support activities. Foreground programs are all on-line, periodic or demand tasks essential for system operation. Foreground programs perform the daily real-time and operator-requested operations. The foreground programs should be protected (protection from modification or destruction of instructions or data) through hardware, software, or procedural methods from programs executing in background.

(2) Batch Processing

Background programs, being the lowest priority or a limited class, execute in a batch mode. This background job stream is initiated by a programmer through a programmer's terminal, typically a keyboard printer or compatible CRT. The programmer interacts with the background monitor through a controversial job control language. Jobs and job control instructions are input from cards or tape; source and object files are maintained on disc and tape; and output is to the line printer, magnetic tape, disk, or other output device such as an X-Y plotter. Using these peripherals and the facilities of the background monitor, the programmer can assemble, compile, load, test, debug, integrate and execute programs.

(3) Assemblers

The assembler converts assembly language source code into object code which serves as an input module to a link and load program. Important assembler features include:

- Macro definition - capability for user to write his own assembler source instructions to define frequently used operations

- Conditional assembly - capability to mark certain source instructions and then to assemble either with or without those instructions. Thus, for example, code useful in test and debug can be assembled in for testing, but out for final integration

User output should include:

- Absolute or relocatable object code

- Source and object listings

- Error messages and diagnostic data

(4) Compilers

The compiler converts high level language source code into object code which serves an input module to a link and load program. While some use has been made of COBOL and ALGOL, FORTRAN IV is

by far the most common high level language. The FORTRAN IV should be compatible with ANSI X3.9 1966 specifications.Furthermore, the following real-time extensions are of value:

- ° Bit, byte, half word, word, and double work manipulation
- ° Interaction with real-time data base
- ° Inter-program communication and control flow
- ° Multi-dimensional arrays
- ° In-line assembly language and assembly language subroutines
- ° Conditional compilation
- ° Capability to call executive services

More and more, FORTRAN is being used for all but the most time critical application functions such as the interrupt driven routines, the routines related directly to hardware, and those requiring a considerable amount of tight bit and byte manipulation. As a result of this extensive use of FORTRAN. the compiler's capabilty to optimize code has become very valuable. The compiler should be multiple-pass with code optimization, preferably block or global, aimed primarily at a reduction in run time, but also secondarily at a reduction in required main memory storage.

As with the assembler, comprehensive error and diagnostic messages are useful.

(5) Utilities

While the term utilities is sometimes used to cover all system support software, it will be used here to cover link and load, test and debug, integration, and editing facilities.

The link and load facility, sometimes called link editor or just loader, is used by the programmer to convert defined object modules into an executable load module. The facility should include the capability to link together individual object

modules which consist of one or more programs that have been compiled and/or assembled. During the link and load process, data definitions external to the individual object modules are referenced to one another and to the system's common data base. Once tested and integrated, the executable load module can become a task in the real-time system.

Thus, test and debug facilities are required so that the user can be sure the program is functioning properly before it is integrated. Facilities should allow the test and debugging of programs in a manner that will not jeopardize real-time operation. In practice, background work including test and debug is usually performed on the back-up computer in a dual computer system. This practice not only insures the safety of the real-time operation, but also means quick turnaround since background in the back up need not vie with the myriad of foreground programs for CPU time. The user should be able to accomplish testing using both test data and real system data. Capability to use real system data in a mirror-image back-up system permits testing in a simulated real-time environment. Important debug capabilities include trace, snapshot, and memory and register alter and dump.

Once the program is tested, the user is ready to add to the system, perhaps as a real-time program to run periodically or maybe a study program to be called on demand. The program may be a new function or a replacement for an existing program. Integration facilities allow the user to define the task to the operating system - to allocate bulk storage and to set up or modify task definition tables in the executive.

To maintain source and object modules, the user is provided with editing facilities. Source editors are often termed source update programs; while object editors are often called library update programs or library editors. Source is usually stored on tapes; while object is usually stored in bulk memory. Facilities should be included to add, delete, or modify specific line or lines of source code via record or sequence number and to obtain an updated listing. Similar facilities

should be provided for object modules where these modules include system libraries such as math and scientific subroutine libraries. Capability should be included to store the modified code separately from the original so that the original could be retained as long as desired.

(6) Display and Data Base Generation

The organization of displays and the data base is rather unique to the electric power control application, and for this reason software for maintenance and expansion of the data base, displays, and logs is usually created by the system supplier rather than the computer supplier. During the lifetime of a system, existing functions and remote stations will be expanded and new functions and remote stations will be added, thus expanding the data base and number of displays and logs. Data base, display, and log generation programs are absolutely essential to minimize the programming effort to maintain any large control center. Details on generation programs are given in the "Display Subsystem" portion of the bulletin.

c. Automatic Start-Up and Failover

The automatic start-up and failover hardware and software is designed to maximize the availability of critical system functions within the constraint of the number of dollars available. Along with this primary goal, a balance must be achieved between two secondary goals: 1) minimize loss of information as a result of switching equipment of systems and 2) minimize the increase in CPU and I/O loading due to the execution of security software. An important and sometimes overlooked aspect in reaching the goal of maximum availibility is the minimizing of failure rate increase due to failures in the hardware and failability in the software that is dedicated to error detection and recovery. The following describes software features and functions related to failover detection and recovery. This software operates in conjunction with the failover hardware and redundant or backup equipment described earlier. The discussion is based on the common symmetrical redundant on-line system - back up system.

(1) Malfunction Detection

The first step in maximizing availability is the detection of errors. Errors can be hardware and software. Hardware errors result from either temporary, intermittent, or sustained hardware failures. Software obviously does not fail, but can contain design and coding errors. Errors must be detected, and recovery action varying from retries to failover must be taken. An undetected error can cascade causing more severe failure of the system and greater difficulty in isolating the original cause.

Some examples of malfunction detection techniques are as follows:

- Data transfer error codes - For example, parity bits are typically associated with main memory reads and such I/O devices as magnetic tapes and disc. In these cases, recovery techniques include retries, restarts, and when required, failover

- Interval timers - Peripheral device failure is often detected through the device's failure to respond to a request after a certain period of time. The elapse of a timer signals the failure to respond, and if multiple retries are unsuccessful, the device would be declared failed. Then depending on the device, device backup or system failover could be initiated

- Traps - Errors such as non-existent memory access, unimplemented instruction, or memory protection violations result in a trap. Depending on the nature of the fault, the trap routine could initiate a retry, a restart, or a failover

- Data acquisition error codes - Error coding such as Bose-Chaudhuri is employed in data acquisition and control communications. Detected code errors can result in retries, backup, or failover, depending on the nature of the situation

Every time an error is detected, the system operator should be alerted via an error message display and printout. Necessary system status data should be included in the printout. Printouts are also helpful for later fault location.

Once an error is detected, the system attempts to recover in a manner resulting in minimum impact on real-time system operations. As indicated in the above examples, a simple retry may be attempted, or restart or failover may be required. Initialization, restart, and failover are discussed below.

(2) Initialization

Initialization is the start-up of the system using an initialized copy of the data base. The stored initialized copy is pre-defined and unaltered during normal system operation. Initialization is useful during factory integration and test, when a clean start can be preferable to using the latest copy. However, once the system is operational, initialization is of little use as a recovery mechanism because the initialized copy quickly becomes outdated and thus the impact on the system would be too great.

(3) System Update

System Update software maintains the latest saved copy of the data used in both restart and failover. Restart and failover may be initiated either automatically or manually. Once initiated, automatic and manual result in the same procedure. Periodically, typically one to five minutes, certain main memory resident data are snap-shot onto both the on-line and back up bulks. Types of data saved by this checkpointing program include dispatcher-entered values such as overrides, limits, and schedules plus certain system status data. Normally, telemetered values need not be saved since they are reacquired when the system restarts. The big question is how often to save the data. The more often data is saved, the less likely any will be lost during failover. However, more frequent updates increase CPU and I/O loading, lowering the ultimate capacity to perform control functions. A typical compromise has been

three minutes, but the answer is really user dependent, and may be varied during the life of the system.

(4) Automatic Restart

Automatic restart is initiated when the possibility exists that the on-line system can recover from the detected error without having to failover. Automatic restart obviously has less impact than failover on the system. The orderly restart of the system typically includes the following sequence of operations:

- Interrupts disabled
- Executive's queue cleared
- Copy of executive and checkpointed data base is read from the bulk to main memory
- Periodic programs added to queue
- Execution begins
- Interrupts armed and enabled
- Operator informed of new state
- Operator allowed to enter new time and date

(5) Automatic Failover

Failover to the back-up system is automatically initiated whenever the master's operation is unacceptably impaired, such as the case if reoccuring traps, or whenever the master fails to update the deadman timer, indicating it is either dead or hung-up. Failover is the orderly transfer of operations to the back up system. Needed peripheral devices, man/machine interface, and data acquisition hardware are automatically switched to the back-up. An automatic restart of the back up is performed, and it then becomes the on-line master. The old master is placed off-line. Typically, automatic failover is accomplished in no more than twenty seconds.

The system operator may observe a malfunction not detected by the software to determine if a failover is required. Manaully initiated failover must follow the same procedure.

(6) Device Back Up

Automatic back up of a failed device is performed in order to retain the function performed by the device. Back up may be to an identical device or to a similar device capable of performing the function. The back up device may be a dedicated back up for one or more operating units, or it may be an operating device that would have to perform its own function plus the failed function. Non critical devices, such as X-Y plotter, will probably have no back up.

When a device fails, the operator should be informed of the failure and the new back up device, if any. The back up should be automatic and require no programmer or operator modifications to the system. Multiple levels of back up should be defined where possible. Of course, the operator must have the capability to initiate the transfer to a back up when he detects a problem.

d. Diagnostics

Diagnostics are programs used to locate hardware failures. Three levels are usually available:

- On-line, run under the operating system
- Off-line, run under a diagnostic executive
- Off-line, stand alone

A diagnostic is designed for a specific device such as a specific type of CRT display unit or for a sub unit such as the main memory of the computer.

(1) On-Line Diagnostic

On-line diagnostics are often called on-line exercisers because of the limited testing that can be performed on-line. On-line testing cannot be permitted to disrupt critical real-time operations. Thus, at most, a test pattern could be output on a device such as one of many

redundant CRT's. In fact, it is often said that the real-time operations are the best exerciser of the system. Generally, on-line diagnostics are of very limited value and are certainly the least important level, the main use being the periodic testing of equipment having relatively low level of use.

(2) Off-Line Diagnostic

Off-line diagnostics are important tools for the maintenance engineer. Typically, when a problem occurs, it is reported by the malfunction detection program or noticed by the operator. Depending on the location of the problem, either the system is failed over or the problem device is transferred off-line. The failed component could be made to duplicate the problem to further identify it. A series of diagnostics can be run under the diagnostic executive to locate the offending device or subassembly. The diagnostic executive also permits multiple components of the computer subsystem to operate in an environment which approximates a simplified operating system. Thus, malfunctions due to interrelated operations may be isolated without the complexity of system operation. Then appropriate stand alone diagnostic is run to pinpoint the problem. Pinpointing is done to the replacement level. Thus, for card replacement the failed card is identified. The existence of a mirror image system greatly facilitates the rapid location of failures. Visible indicators showing the present assignment (on-line or back up) of every device should be included to facilitate maintenance and testing.

12. Configuration Selection and Performance Analysis

Configuration selection and performance analysis are based on the scope of the application as defined by the user in his purchase specifications. The user's specifications should define the functions to be performed, describe the desired capabilities and features, and should define both the initial and projected ultimate size of the application. This information allows prospective suppliers to size up the application, select what appears to be the appropriate configuration, and analyze its performance against both initial and ultimate

requirements. Modifying and reanalyzing as necessary, the supplier arrives at his most appropriate and cost effective configuration complete with estimated performance data.

a. Sizing Up the Application

For the Vendors to be able to size up the application, quote the appropriate configuration, and provide pertinent performance estimates, it is necessary that the buyer define the initial and ultimate scope. The key parameters defining the scope as related to the computer subsystem are detailed in the following paragraphs.

(1) Data Acquisition Requirements

Computer main and bulk memory requirements are a function of the number of remotes scanned, and the total data scanned. CPU and I/O loading are a function of the amount of data scanned per second. Thus, the buyer should specify (for both initial and ultimate levels) each remote to be scanned, giving the number of status entries, status entries with MCD (Momentary Change Detection), analogs and accumulators, and the scan rates. Any special features such as Sequence of Events should also be defined.

(2) Man/Machine Interface (MMI) Requirements

The important MMI parameters are the number of independent CRT monitors and the desired update rate. The CPU and I/O loading due to MMI is primarily a function of the number of CRT updates per second. For example, the buyer may request 12 CRT's initially, plan on 16 ultimately, and require a four-second update rate. Thus, if all CRTs had updating displays on them, three updates per second would be required initially and four ultimately. The total number of displays impacts bulk storage, but the Vendor can estimate this number based on the number of remotes, and the application programs to be included.

(3) Application Requirements

The specific functions to be performed should be defined for they have major impact on main memory, size (particularly overlay area), CPU loading,

and bulk I/O traffic. The required capabilities and features should be specified. For example, is the load flow to run on real-time data, study data, card inputs, or all three? What is the size of the load flow (number of lines and busses)? What features such as automatic tap changing are required? How many contingencies are to be analyzed per hour? When such requirements are not specified, great variations in vendor interpretations may result.

(4) Availability Requirements

The most typical way to define required availability is to state the desired level. For example, the calculated availability of all critical functions shall be 99.9% where critical functions consist of 90% of the data acquisition, automatic generation control, and man/machine interface. Another common approach is to require a field test of 90 days demonstrating 99.8% availability of critical functions. Short-term test requirements are almost always less than calculated values - expected performance over the lifetime of the system.

To insure a certain level of availability, it may be necessary to specify a dual redundant configuration for all critical components, and to request an availability diagram and calculation. Most proposed dual redundant systems will calculate out to 99.9% or better.

(5) Loading Requirements

The buyer should request CPU and bulk I/O loading calculations for both initial and ultimate sizes. The calculations should be for normal average loading, based on reasonable user assumptions of normal activity. The vendors should be required to detail any variations from these assumptions. Unreasonable criteria may substantially increase the cost of the system, bias the performance of the system, or cause some bidders to take exception, thus losing the comparison. The buyer should state the range of loading he is looking for. While individual requirements will vary, depending on the number of functions the user plans to add to the system during its lifetime, and the un-

certainty of the ultimate scope, typical figures are 40% to 50% CPU load initial and 60% to 70% CPU load ultimate. For each buyer it is a case of determining the appropriate balance between 1) system response and expansion capability and 2) dollars to be spent.

(6) Expansion Requirements

Spare main and bulk memory are major expansion parameters of the computer subsystem. Certainly, sufficient main and bulk memory should be supplied to meet the ultimate scope of the application. Typically however, for the user's own use, and as a margin of safety, at least 10% spare main and 25% spare bulk (10% and 25% above initial requirements) should be requested for the initial system, and field expansion should allow for at least 25% spare main and 50% bulk over the defined ultimate.

(7) Background Usage.

In order to have proposed the appropriate types and numbers of programmer I/O terminals and I/O equipment, the buyer should either specify the types and numbers desired or describe the expected level of program development, system maintenance, and expansion activity.

(8) Special Features

The final major items to define are the special features. For example, is this system part of a hierarchial structure such that communications with other computers are required? What is the nature of these communications? What is existing equipment to be interfaced with?

b. Computer System Selection

Based on a specification that scopes the application, a system supplier is able to select the computer having the necessary hardware and software capabilities and features, configure the computers to provide the required CPU power and availability, and select the types and numbers of peripherals to provide specified functions at a specified level of availability.

(1) Computer

Most system suppliers have a number of computers or a number of models of the same computer from which to select. Typical variations within the models include main memory speed, memory size limit, instruction speeds, I/O bandwidth, floating point implementation, system software features, and supported peripherals. Different computers vary by these factors, and many more, including word size.

The selection of the computer is not really a separate step from the selection of the configuration, because the resulting configuration may consist of a number of different computers or computer models.

(2) Configurations

The dual redundant system is the most common configuration. In this case each side consists of a single computer. This single computer must contain all the desired real time features and perform all the functions specified for at least the initial scope. In another type, each side consists of multiple computers: one acting as the primary machine containing all the necessary real time features, doing a portion of the required workload, and scheduling the workload for the others, where each of the others acts as a processor dedicated to certain pre-defined tasks. Such dedicated tasks include data acquisition, man/machine interface, and large computational applications. Dedicated processors can be cross-strapped to work with either primary machine. Cross-strapping can improve availability, but can only be employed where interfaces between the machines are such that a failure in the one system cannot cascade into the other.

A number of earlier installations consisted of a single computer with analog backup. Such an approach minimized initial cash outlay and provided a field proven back up for the system's key function, automatic generation control. Today, such an approach is not the favored approach for a large control center, because:

- A backup computer system has proven extremely useful for system maintenance and expansion, running of off-line study programs, and troubleshooting

- Digital Computer Control is field-proven

- Computers now provide critical security functions that cannot be backed up by analog equipment

- Cost of the back up system is a relatively small percentage of the cost of the entire control system

Another feasible approach would be a distributed processor configuration. In this type configuration, there is no symmetrical back up system to the on-line system. Backup is achieved by either having one computer be a dedicated backup, or by having a degraded backup, with a computer having to do its own function and the function of the failed processor. Each processor has its own set of tasks, but none usually acts as a primary controlling machine. Interprocessor and intertask communications and access to common data is through some combination of communications channels, shared main memory, and shared bulk storage. The present risk in selecting such a configuration is that:

- It is the least common approach in electric power control applications

- Its performance relies heavily on the success of the communications and resource-contention schemes

- It does not provide the mirror image system that is so useful in trouble shooting and program testing

- The availability of the individual processor must be much higher than that of a large computer that could handle the entire application in order to have the availability

of the distributed processor configuration approach, that of a dual computer system

° Each computer must be uniquely engineered and SYSGENed, unless they are all over-sized to keep them common

With the performance of hardware and cost of engineering and programming going up, this approach should not be attractive in the near-term future.

(3) Peripherals

The selection of peripherals is also not independent of the computer selection, because supported peripherals may even vary between computer models. The key factors in peripheral selection are overall workload, the user's plans for his own programming and expansion activities, and special applications. The selection of the type, number, and storage capacity of the disks, is directly related to the defined workload and the computer configuration. The programmer terminal equipment, the speed and number of magnetic tape units are directly related to the planned programming and system expansion activities. Historical data storage requirements may necessitate additional disk capacity or magnetic tape units. Special application programs may require an X-Y plotter or trending capability.

(4) Given the options above, how does the system supplier arrive at his best solution? Typically, he will ball park the CPU loading required by the average number of remotes and amount of data to be scanned per second, the average number of CRT's to be updated per second, and the total application program loading - the programs required, the sizes of the models, the frequency of execution, and the special features required. If all these requirements (ultimate plus spare) can be accomplished by a single computer (computer standard to that supplier) having the necessary real-time features, then a majority of suppliers will select the symmetrical dual redundant configuration. This approach is the most field-proven, least complex, and the easiest to field expand to reach the ultimate scope.

However, there are two other possibilities. The supplier may offer a dual, redundant system that meets the initial requirements and that can be field expanded by the addition of dedicated processors, to form a multiprocessor configuration capable of meeting the ultimate requirements. The advantage is the reduced initial cash outlay and shorter initial delivery. The disadvantages are the extra cost involved in field expansions over factory implementation of the entire system, the greater interruption and risk involved in field additions, and the loss of the added capability prior to the field expansion. Because of the above reasons, this approach has been planned more often than it has been accomplished.

The second possibility is that the supplier will quote a multiprocessor configuration even though he has a single computer that could do the job. He may do this if he can achieve significantly reduced hardware costs, or if the smaller computers were better suited to the real-time application. These advantages must be weighed against the increased risk and complexity of the solution.

When the scope requires multiple computers, the supplier may be able to quote a dual, redundant multiprocessor configuration, if his computers are designed for that purpose. The function of the dedicated processors are to off-load the primary computer. The scope of the data acquisition, man/machine interface, and application computations determines the number and capability of the dedicated processors and division tasks. Cross-strapping of redundant processors between primary computers is employed where possible to increase availability.

c. Validating the Selection

Having made an initial selection of computer subsystem equipment and configuration, the prospective supplier should calculate expected performance. The key computations are CPU loading for each processor and I/O channel loading for each major channel (within the computer subsystem, bulk I/O loading is the most critical). In determining the average percent CPU and I/O loadings under normal conditions, the average loading due to each task should be specified and all

assumptions should be defined. Average loading rather than peak loading is calculated, because the peak load is always 100%, i.e., the CPU is either executing or idle. Furthermore, and more important, whenever there is active a background task or low priority, long running-study, the CPU will be 100% loaded (assuming no other resource constraint exists) until the task is complete. It will use all spare CPU time.

The supplier must also define the information flow and insure the integrity of the data. Communication protocol between processors and peripherals must be established. Where common data is shared among processors, contention procedures must be established.

Availability diagram and calculations should be made. The supplier should be able to state that there is no single known hardware contingency that could cause the complete loss of any critical function. The supplier should also describe the precautions taken to isolate the on-line system from the back up system so that a failure in one cannot avalanche into the other.

The analysis that each prospective supplier prepares not only allows him to establish his best computer offering, but also helps the buyer to determine the adequacy of the proposed system and the relative comparison to other proposed systems. The final measure of a proposed computer subsystem includes this analysis plus other key considerations such as:

° How experienced is the supplier in providing such a level system? What is the past experience of my company and other companies in dealing with this supplier?

° How field-proven are the approaches the supplier proposes?

° How much does the computer subsystem cost? What provisions for future expansion have been included?

° Does the hardware and software system provide all the necessary real-time and user features?

- Does the supplier support the entire offering with documentation, diagnostics, spare parts, training, and factory testing?

D. Man/Machine Interface

1. Introduction

The Energy Management System as conceived in the mind of today's power dispatcher does not manifest itself as sophisticated algorithms or a complex hardware configuration but rather as a flexible man/machine interface subsystem. Although the design and implementation phase may take two to three years, the man/machine interface subsystem will remain visible and become the primary criterion for system acceptance and successful implementation for several years.

In order to adequately design a man/machine interface, the designer must be familiar with the work of the dispatcher. The primary objectives of the man/machine interface is to speed and strengthen the dispatcher's decision making process and to alleviate him of the routine efforts involved in monitoring and logging. Consideration must be given to the present role of the dispatcher within the organization. In addition, if the system achieves its primary objectives, the dispatcher will have additional time available for future functions that must also be considered.

In considering future functions, one must also consider future changes within the organization that would enlarge the dispatcher's sphere of operation. Typical of these are load management functions, trouble dispatching, etc. These future functions are most difficult to define in specification terms so that typically the specification writer will indicate the type of function and then allocate a block of system resources to be used for all future functions.

It is important to keep in mind the differences between required functions and those that would be nice to have. A common pitfall in many systems is that the computer system is used to perform not only the essential functions but many of the record keeping functions that simply replace a notebook and telephone. This latter type of function is quite acceptable as long as it does not detract from the resources being utilized to provide for the essential functions of monitoring and control.

All electric system Borrowers, while charted with the same responsibilities, are unique in their procedures and approach to the problems. For that reason, the man/machine will be unique to each individual company; that is, the implementation of the various similar techniques will be different depending upon the requirements at each company.

All vendors have a preferred method of satisfying the requirements of the man/machine interface, but it will most probably be modified to some degree for each utility. It is in the best interest of both the end user and the vendor if these modifications can be minimized so that basic modules of the man/machine approach can be similar across many different projects.

In designing the man/machine interface subsystem, the primary goal should be to keep the method of operator/ dispatcher interface as simple as possible, requiring the minimum number of actions by the dispatcher. The system should be designed for the system dispatcher with his influence playing a major part in the system design.

In order to gain acceptance at the earliest possible time by the dispatcher, an attempt should be made to adhere to the basic procedure and methods used by the dispatcher. A drastic change in operating procedures will result in a much harder acceptance period once the system has been installed. For example, if the dispatcher has traditionally called substations by name, and now he must number each substation and refer to it by number, the system acceptance period will be more difficult. Therefore, if procedures exist that are being implemented in the man/ machine subsystem, close adherence to the familiar procedures should be maintained.

In addition, specification writers typically write the specification considering the efforts during the first six months of system use. An attempt should be made to include facilities that the dispatcher will use after he becomes quite familiar with the basic operation of the system. Typical short cuts for display request can be built into the system while normal procedure may be to proceed from a menu to a substation. It is quite possible to provide tools that will let the dispatcher move from substation to substation without returning to the menu or the top level of display. This type of consideration should be made assuming that the dispatcher will become

quite familiar with the operation of the system within the first six months of its use.

When determining the requirements that are unique to your system, expansion is an obvious consideration. Expansion of the man/machine system may take place in many dimensions. Typical expansion that affects the man/machine interface subsystem is expansion of the power system itself. Additional data points, remote terminals, generating stations, etc., will be required during the life of the system. This will impact the number of displays, the amount of data stored, the mass memory, central memory, and access time for data retrieval. Typical of the expansion seen in many utility companies is the need to disseminate data to other users outside the dispatch center by use of high speed communication circuits to remote CRT's. This function will again affect the basic design and should be considered in the initial design of the system.

The most important type of expansion is that which is not dependent on system growth but involves the addition of new functions and capabilities to the Energy Management System. This type of expansion is the most difficult to define. Again, ability should be included in the initial system to allow for both physical capacity within the Energy Management System, and the ability to link displays to data files created by such future applications. This is perhaps the most important and most frequently overlooked type of expansion that will be required.

As stated above, the man/machine interface is unique to each user. It should utilize basic modules that are well supported and field proven by the Vendor. But it is to be tailored for each user's particular requirements. For that reason, it is desirable to keep the linkage between the system and the man/machine interface subsystem flexible, so that the Vendor can implement his basic system design and still provide a subsystem that is tailored to meet the specific needs of the user. This provides an economic advantage for the user.

The load on the man/machine interface subsystem fluctuates greatly. It varies over a wide spectrum based upon the operator demand and system initiated events during a period of time. As a result, it is necessary to provide as much reserve real-time capacity as possible within the system for heavily loaded man/machine periods. Many of the systems being provided today isolate this man/

machine load within a specific CPU dedicated to the support of man/machine interface requirements. This technique allows the fixed system overhead involved in data acquisition and communications along with periodic functions to be separated from the demand oriented functions of man/machine. Where the fixed functions are more easily predicted, the demand functions will require sufficient capacity within the system so that the performance criteria will be adhered to.

The response of the man/machine interface subsystem is most important during the heavily loaded periods, specifically, during system disturbances when the computer system is handling a number of alarms, display requests, and restorative procedures. It is the time period when a system, that is marginal in its real-time capacity, will become loaded down and be more of a hindrance to the system dispatcher than an aid. For the reasons stated above, it is most important to define and specify terms that will insure the correct responsiveness of the system. The parameters that provide for this responsiveness must be specified in a quantitive manner. System timing and loading parameters should also be identified to the man/machine subsystem and consideration of expansion should be included.

2. Data Considerations

The interrelationship of the data base and the display files in a real-time system is critical. The manner in which the data is stored, arranged, accessed, and displayed, can be the controlling factor in the viability of the real-time system. Typically, the data for displays should be resident in the data base; that is to say, for most types of information, the data should be stored and accessed upon request of a display, rather than calculated at display request time. This results in a better response time.

Assuming that the data for display is resident within the data base, significant differences in display response times will be obvious, depending upon the location of this data. A typical one-line diagram with telemetered values associated with it stored in the central memory resident data base will allow a rapid response time for this type of display. On the other hand, data with a low utilization factor that is typically stored in mass storage, and that resides in several different data files, or data that must be accessed from a remote computer upon demand,

will have a much slower response time. When considering the responsiveness, consideration should also be given to the location and type of data being required.

The data flow within the man/machine subsystem is heavily dependent upon the update rate required. The subsystem design for the man/machine lends itself to the isolation of the CRT update rate from the overall system data base update. If the system scan rate is dependent upon the information shown on the displays, the communications time from the remote terminal through the man/machine subsystem is difficult to predict because of the varying load that will be imposed on the man/machine subsystem. On the other hand, if the scanning function is allowed to be free-wheeling or asynchronous, and the man/machine function updates at a regular periodicity, the system load can easily be calculated for a particular set of system parameters. This type of analysis allows the system designer to properly balance the utilization of system resources throughout the system configuration.

3. Techniques Used

Among the decisions encountered during the specification or design of a man/machine Interface Subsystem are ones involving the techniques used for cursor control, display selection, alarm philosophy, and device control. Each company seems to devise its own particular and unique approach for selecting displays, entering data, controlling devices, etc. These unique approaches, while they allow the specification writer a creative license, usually costs him a great deal in terms of unique development on the part of each Vendor. Preferred techniques proposed by the Vendor during the initial investigation phase should be allowed for and encouraged in these areas. The specification should encourage each vendor to discuss the preferred techniques for his system.

a. Cursor Control

Cursor control can be implemented in one of several methods. The basic and most fundamental method is that of a group of cursor control buttons on the keyboard. These are used to position the cursor to the desired location for display selection or data entry or device selection. Various other mechanisms are used for this function and include a joy stick, light pen, or a track ball. Each of these supplemental cursor control devices has advantages and disadvantages. The

advantages lie primarily in the speed with which the cursor can be moved. The disadvantages lie in the additional mechanical and electronic equipment utilized in the device itself. In the case of the joy stick and the track ball, both mechanical and electronic linkages are required. In the case of the light pen, electronic and/or photosensitive techniques are used to position the cursor. The ease with which the operator can use these devices over a long period of time is important in their selection. It should be pointed out that each of these three types of devices is supplemental to the basic cursor control cluster of the keyboard. The use of the various tabbing and protective features in modern CRT display subsystems allows enhancement in the use of the cursor control cluster. By tabbing to specific data entry or select points, the time involved in using the cursor control cluster may be less than that involved in using the other devices, without the need for adding the disadvantages of these devices to the system.

b. Data Entry

There are two typical classes of data entry. One is the classical function of entering data into a format. A typical data entry procedure used is to move the cursor to the desired value, enter the new data, and press an "ENTER" function key. Many Vendors use the protect mode of the CRT to prohibit the cursor from residing on any position other than an enterable field, with the format in the protect mode, the cursor will automatically jump to the first character position of the next enterable field. This greatly facilitates data entry.

Verification of the entered data then becomes necessary. Partial verification is inherent in that the modified values appear on the screen prior to pushing the "ENTER" key. When the "ENTER" key is pushed, the value is redisplayed in a different color to confirm the acceptance of the value by the system. There are several classes of verification used in systems. For instance, alphas within numeric fields are checked, some form of limit checking for reasonability of the value is typical, and, in many cases, the user programs, such as the AGC functions, perform their own individual program validity checking. In the first two cases, incorrectly entered data values can be changed to a flashing red, while in the third case, the indication of the incorrect data can be defined by

the verification program.

Several values may be entered simultaneously on a single display. As the "ENTER" function key is depressed, all of the changed values are checked for validity. If any one of the values is determined to be invalid, none of the entries will be accepted. The invalid data fields or field can be shown in flashing red and the operator may correct these and again push the "ENTER" key.

The second type of data entry is manual replacement of data that is telemetered. It is not necessary to use the manual replacement approach on dynamic data since the update processor is constantly updating it from the data base. In the case of manually replaced data, the method is a little different. The manual replacement function prevents the updating of the value in the data base until the manual replacement status is changed. The data is placed into the data base and it remains there until the telemetered data update function is reenabled. To perform this operation, the dispatcher positions the cursor on the point and presses "MANUAL REPLACE" function key. The new value or status may be entered and the "EXECUTE" key depressed. The fact that the value has been manually replaced is noted by either a character next to the data point, or a unique color in which the data is shown.

c. <u>Alarming</u>

The alarm functions of the man/machine interface may be implemented using alarm printers and CRT display equipment. Any alarm that occurs in the system is printed on the alarm printer and notification is given with the alarm light or some other visual effect on the consoles. The "ALARM SUMMARY" button is used to present the summary display of all alarms. These alarms may be categorized according to geographic area or jurisdictional responsibility. As an alarm comes into the system, the device or data value on the appropriate one-line will be shown in a distinct color, normally flashing red. An alarm message will be output to the printer and usually an audible alarm will be sounded within the system. Upon displaying the alarm summary, the dispatcher would see an alarm message identical to that printed out on his logger. It would be in a distinctive color, typically

red, with some portion of the message flashing to draw the operator's attention to it. The dispatcher then would have the ability to acknowledge the alarms that were still in the flashing state upon the CRT screen, through the use of an "ALARM ACKNOWLEDGE" button on the keyboard.

In addition to the alarm summary, other typical displays such as the inhibit summary, the abnormal summary, and tag summary can be displayed upon request.

d. Display Access

There are several methods for accessing displays: 1) directly through function keys, 2) an index or overview selection, 3) paging buttons, 4) direct "poke point" linkage, and 5) numeric or alpha entry.

Typically, there is a system index from which a number of display pages can be accessed directly. The number of displays accessed form the system index is limited only by the number of pages required to display the entire menu list. Secondary menus can be utilized for categories of information that require more indices to be specified to allow direct access to large numbers of displays or formats. This begins to form the pyramid of display files. Paging forward, backward, up, down, right, and left can be used to move either laterallly in a level, or vertically in the pyramid. Paging sequences should be determined at the time the displays are generating and should be independent of any other direct display access linkage.

Direct display to display linkages should also be provided within the system. These are usually function provided through the use of On-line Display Generator or a picture compiler. This type of linkage can be defined by the person generating the display at will and is usually not limited, except by the number of "poke points" possible on the display. As an example, these display linking "poke points" can be created at such places as the first letter of a station name to allow linkage from an overview to a station On-line. Numeric key entry works especially well if the dispatcher is accustomed to referring to the substations by number. If not, it is still advantageous to have as a tool because the dispatcher will begin to remember some of the display numbers very quickly.

The numeric selection method then becomes a short-cut for him. The entry of alpha characters for identifying displays is more complex for the system of software and should usually be avoided.

Typical of the station oriented displays are one-line diagrams which are limited graphics representation of the substation single-line diagram.

Another type of display is the administrative format. This display is an alphanumeric tabular format. The information on this display is a summation of the data base and usually contains the current value of data, the high and low limits for data monitoring, conversion factors, as well as the position of all status devices corresponding to the normal status. In addition, several other conditions are usually shown which indicate whether the value has been manually replaced, inhibited, tagged, etc. The administrative format is used to change limit formation and the other data associated with the points. This is accomplished using the cursor positioning capability of the system and the "ENTER" function key. Device control is not normally allowed from these formats. Another type of station display is typically a one-line presentation of the results from a State Estimator or other application program. Here the operator can enter several lines of information which is saved and displayed whenever the format is recalled. Entry into the comments page is accomplished by typing the message in the area provided and depressing the "ENTER" key. The previous messages may be modified by making the changes and depressing "ENTER".

Other types of displays are the point summary displays, which include the alarm display summary, the abnormal summary, the inhibit summary, and the tag summary.

Additional displays such as system overviews, indices, and transmission line diagrams, can also be generated, and follow the same basic criteria for control and data entry.

e. Supervisory Control

Most systems allow for the control of devices from the keyboard via the one-line diagrams. Normally, the procedure is as follows. The appropriate substation On-line is selected. The cursor is positioned on the

device to be controlled and then the appropriate function key is depressed. The appropriate function keys may be, "TRIP", "CLOSE", "RAISE", "LOWER", "TAG-SET", or "INHIBIT SET", etc. A verification message should then appear on the CRT indicating that the point has been selected and the operation to be performed. The dispatcher then presses the "EXECUTE" key. Upon receipt of the corresponding change from the RTU, the device color and character change on the CRT and message "OPERATION COMPLETE" should be shown on the verify line. A time period check is usually initiated upon selection of the action and verification. If no action is taken before this time period expires, the point will be reset and the display returned to the initial status. Similar action is taken if the dispatcher pushes the "CANCEL" key instead of the "EXECUTE" key. If no confirmation of control action is received for a period of time after pushing EXECUTE, an appropriate diagnostic message should be output on the verify line.

The tag function and the inhibit function can be performed in a similar fashion.

Control of tap changers is a typical application requiring the use of RAISE and LOWER keys. The procedure is as described above except upon pushing the EXECUTE key, confirmation of the action is evidenced by a change in the data value representing the tap position. The point does not automatically clear. It remains active awaiting another tap change command as indicated by another operation of the EXECUTE key. The point is cleared automatically upon exceeding the time delay or upon execution of the CANCEL key.

f. Display Generation and Maintenance

Because of the number of displays involved in the typical systems today, a display generation capability that allows the user to easily build or modify existing displays is mandatory. Most vendors have found it necessary for their own use when building display files for systems with as many as 10,000 displays. The display generator is a significant and integral part of the man/machine system. The display generator should provide the ability to link to data values and stored in the data base as well as the ability to link to complete predefined data files. It must provide the ability to link display files

for interdisplay linkages, create linkages for scheduling programs, create linkages for passing a parameter to a program, and define ASCII character strings for display. The display generator should allow the operator to specify function key linkages at the time of the display generation. The key linkages are normally used to define which display to present when a key is depressed. Although techniques vary, the display generator is usually used first to build a static format, and then identify specific points on that format, to link it to the data base.

The Display Generator provides the linkages between an existing data base structure within the system and the display. The data base structure is created through the use of the Data Base Generation software module, then it is maintained and updated or edited via the use of Date Base Maintenance software. Both the display generator and the data base generation and maintenance software should be considered key and integral parts of the man/machine system.

E. Data Acquisition and Communication Subsystem

1. Introduction

The Data Acquisition and Communication Subsystem (DACS) has as its prime function the transfer of current status of the electric system from the field to a digitized data base in a control center computer. Through use of that data base by Man/Machine and Applications Software, the control center operators are able to monitor and control the electric system according to company established operating procedures. The control center may be designed for energy control, SCADA functions, or a combination of the two. SCADA control centers provide the typical functions of monitoring, logging, and supervisory control. The Energy Control Center typically provides for the functions of generation control, security analysis, study and logging applications, and may also provide the SCADA functions.

The DACS is the interface, the data and control path to the generating plant and substation equipment, to regional control centers, to neighboring utility control centers, and to a power pool control center. In short, it is the interface to the external world. From a hardware standpoint, the interface is composed of a communications

interface between the computer subsystem and the communications circuits. The remote end of the communications circuit may be connected to programmable or hard-wired logic terminal units or to other computers. The orderly transmission of data between the energy control center and the terminals requires that communications line discipline or protocol be maintained, usually by mutual operation of the hardware and software.

The Data Acquisition Software activates and controls the operation of the DACS hardware. It will request data from the various terminals as required to support the operational needs of the other software in the energy control center. It will process all received data and create a data base which presents a digitized image of the electric power system, and which is accessible by the other software. The Data Acquisition Software will also process requests from all other software for transmission of supervisory and generation control commands to remote terminals and for transmission of data/messages to other computer centers.

In some systems, data concentrators or unmanned submasters may be utilized to reduce communications costs by routing a number of remote terminals through one larger pseudo terminal. Alternately, the same benefit can be attained by party-lining the remotes on one communications circuit. Regional Control Centers may provide this function in addition to their normal role as the Supervisory Control (SCADA) Center for the region. The interface to the company's business computers can be used for billing or service functions.

The purpose of this section is to introduce the reader to the fundamental requirements for the DACS and the design approaches that might be used. The material presented includes an overview of the design of a DACS, descriptions of the hardware elements and of the software functions. System performance and several design studies/trade offs are discussed. The discussion presented herein is intended to expose the design options rather than a single design approach. It is oriented to the questions - What to consider in defining requirements? What hardware techniques are available? What are the software functions? The information presented is applicable to the utility that intends to provide the systems engineering/integration function as well as for those utilities (the majority) that will procure the system from one of a number of qualified suppliers.

2. Subsystem Design Overview

There are many options at the system level that have impact on the requirements for the DACS. Is the energy control center to be interfaced directly to the Remote Terminal Units, or will the interface be to Regional SCADA Control Centers? Does the Energy Control Center interface to other Utility Energy Control Centers or a Power Pool Control Center? Are the utility's off-line computers to be used? It should be obvious that before meaningful design of the Data Acquisition Subsystem can begin, the system level design concepts must be formulated.

It is important to understand that the requirements of the Applications Software may also impact the design of the DACS. The electric system is an analog network represented by parameters that are dynamic and continuous. The representation of the electric system in the control center cannot be 100% faithful since the control center acquired data from the electric system on a polling or sample basis over geographically distributed communications channels. Thus, the data is discontinuous; there is time skew between data; and the current state of the system is now instantaneously available at the control center. These effects are a result of the data acquisition process. Special techniques have been used to minimize the age of data and the time skew between data to satisfy applications software requirements.

While there are many possible designs and configurations for a Data Acquisition Subsystem, they all have certain basic equipment in common. Figure II-1 presents a simplified system which includes most elements of a Data Acquisition Subsystem. The portion of the Data Acquisition Subsystem which resides at the Energy Control Center includes the following major elements:

- ° Communications Interface Unit (CIU) - provides a path for data and control signals between the computer subsystem and the communications channels. The control signal path typically utilizes the direct I/O capability of the computer, while data is transferred in a parallel, direct memory access mode. Small systems with low data rates may use a less expensive serial data interface into a multiplexer channel in the computer subsystem.

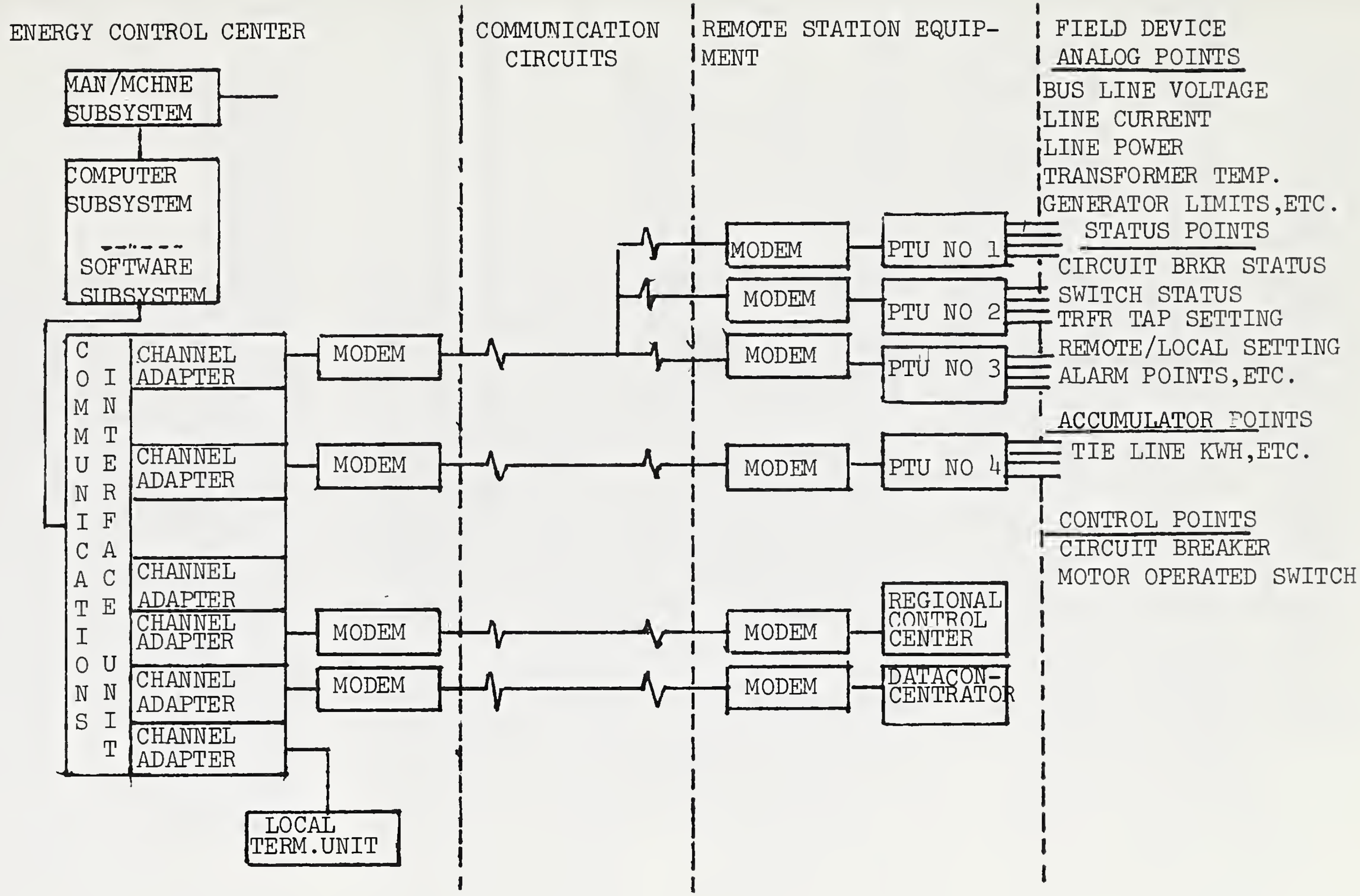


Figure II-1 Typical Configuration of a Data Acquisition ubsystem

- Channel Adapter (CA) - provides for buffering of data, (both inbound and outbound), message formatting/un-formatting, addressing checks, transmission protocol, and error checks

- Modem (Modulator Demodulator) - provides the digital to analog transformation necessary for the transfer of data over the communications circuit

- Programmable Remote Terminal Unit (PTU) - provides the electrical interface to the field device sensors/controllers. Responds to requests for data from control center. Processing and control logic is provided by an internal microprocessor. The PTU may be fielded and/or factory programmable

- Local Data Unit (LDU) - similar in function to PTU, but is located at the control center. May have parallel data path to the computer subsystem

- Remote Terminal Unit (RTU) - a non-programmable remote terminal unit

The design of a DACS for a specific application must be based on satisfaction of a wide range of requirements unique to the application. These requirements originate from many sources:

- Company operating policy

- Physical and geographical characteristics of system

- Other control center functions, in particular applications software

- Dispatcher needs

The list could be extended to more completely reflect the uniqueness of each control center. Subsequent sections will explore some of these requirements and how they might be satisfied in a Data Acquisition and Communications Subsystem.

3. Data Acquisition Requirements

The operation of an energy control center is fundamentally dependent on the acquisition of data from the system under control. It is only through manual or automatic evaluation of the acquired or calculated data that intelligent decisions may be made relative to the control of the system. This concept is not new to the control system designer, but what is frequently given inadequate treatment is the specific, written definition of the requirements for acquiring data, for usage of the data, and for control capabilities. This definition is critical to system design.

Of primary concern is the definition of the characteristics for each data point to be acquired. Data characteristics can be defined in two broad categories: data point type and data point attributes. This information not only will impact the design/size/cost of the equipment (hardware and software) in the Data Acquisition Subsystem, but will also have similar importance to the other subsystems of the Energy Control Center. In particular, the Computer Subsystem and the Applications Software are impacted by such data.

The definition of data requirements must address the system in several phases. First, the requirements must be projected at the time the Energy Control Center is to become operational. This is usually one to three years in the future. Since the system expansion plans (forecasts) are reasonably valid for that period, the near-term data requirements can be accurately predicted. However, the magnitude of specific data required for the initial system data base makes even this a sizable undertaking for most utilities.

The second phase for which data requirements must be defined is some arbitrary point in the future. Typically, this will correspond to the expected useful life of the control center equipment, particularly the computer subsystem. A period as short as seven years has been used. This corresponds to the historical lifetime of older generation equipment. Current state-of-the-art hardware design provides a longer useful lifetime. A longer period of 12-15 years is possible due to the increased durability and maintainability of the modern generation computers. Utility companies should also consider the rapidly changing technologies and their probable effect on the life of the control center equipment. The expandability

of the equipment to accomodate these new technologies will be a major factor in determining when the equipment will become obsolete.

The primary purpose of defining the second phase data requirements is to define the expansion required of the control system. Again, this has prime impact on the computer subsystem. Overstatement of requirements, while clearly preferable to understatement, may unnecessarily increase the cost of the system by requiring expansion capabilities that will never be used. The utilities current growth forecasts should be used to make this project a useful one. Specifying unneeded expansion capability may also reduce the number of Vendors capable (or desirous) of supplying such a system, thus offering the utility fewer proposed designs from which to select.

a. <u>Data Point Types</u>

The definition of the requirements for acquired data must be stated in the form of point counts for each RTU in the system. The counts must be given for each point type. The different major categories of point data types are described below:

° Discrete Input - A point having one or more discrete states. May be used for alarm, indication, sequence of events, or device status. Memory status points may be required to retain knowledge of multiple device operations (such as breaker trip-close-trip) between master station scans. Extremely high security applications might use latching status which remains set until a reset is received from the control center

° Analog Input - A point that is represented by a variable analog signal. May be used for voltage, current, KW, temperature, and other analog measurement.

° Accumulator Input - A point that is accumulating or counter type measuring device. Kilowatt-hour readings are typical accumulator inputs

° Control Output - Interposing relays that are actuated from the control center to operate field devices such as circuit breakers

There is other information relative to each data point that the utility must provide during the development phase as defined below. Requirements in the Man/Machine Subsystem for display of data and alarm conditions are important basic needs for this data. Much of this data is dependent upon the selected Vendor's system design,and will reflect the operational philosophy desired for the Energy Control Center:

- Name - The English text name for reference to the data point on CRT displays or printed logs

- Color Coding - The manner in which data point is to be presented (color, flash inverse color, etc.) for various system conditions represented by the data

- Alarm Procedures - Messages to be displayed and or logged when data point goes into an alarm state. Multiple alarm list displays may be used to segregate alarms by dispatcher function, e.g. transmission, distribution, etc. Data points may be logged on one or more lists. Similarly, alarm messages for the data points may be logged on one or more printing devices. Audible/visual annunciators may be activated to alert the operator. Different procedures may be used when points return to their normal state

- Data Usage/System Correlation - The usage of a particular data point within the computer subsystem is not usually of direct concern to the Data Acquisition System. This information must be developed to define to the supplier the correlation of the data points to the electric system and their usage in the various applications software functions. In some systems, a data base management technique may be used where structured identification numbers are assigned to each data point. In such cases this assignment is of importance to the design of the data acquisition subsystem software

Not all data point information is pertinent to the specification phase. Development of some of the information can be deferred to the implementation phase. However, the specification of requirements and the development of data to support system implementation is a substantial undertaking even for the smaller utility.

- Analog Output - A set-point or desired value to be used by a local device controller. Some generation control approaches send desired generation to the generator control unit as an analog setpoint.

Appendix C provides additional information related to the electrical, mechanical, environmental, reliability, and security characteristics of the hardware

b. <u>Data Point Attributes</u>

The definition of data point attributes is in many cases a subjective process. The following describes the major data characteristics which must be defined/considered:

- Range of Data - The maximum/minimum values (counts) from the sensor, the scale/bias factors required to convert the values to engineering units, and the dead band within which no change will be recognized.

- Frequency of Acquisition - The maximum age allowed for data points in the data base of the control center computers. Report by exception techniques can sometimes satisfy the requirement for current data without periodic scans. Typically, data used in generation control is acquired at two second intervals, as is the status of breakers and other devices important to system operation/security. Other data is acquired at intervals of 10-30 seconds.

- Time Skew of Data - The maximum acceptable period of time between the sampling of various data points of a set. This is important in several cases. For instance, where there are several remote terminal units party-lined on one communications circuit and data is to be acquired from each unit for applications such as generation control. Even when no party-lining exists, applications such as state-estimation may have time skew requirements that cannot be satisfied by the available hardware without special scan techniques.

4. Typical Hardware Elements

This section includes a description of the two major hardware elements or end items in the DACS: the Communications Interface Unit (CIU) and the Programmable Terminal Unit (PTU). Brief discussions of the communications media and of the communications message standards are also included. Both the CIU and PTU can be microprocessor based units. The micro processor is the key to many important capabilities:

- ° Adaptability to different message standards
- ° Multi-use circuit cards
- ° Local processing and control
- ° Low cost maintenance
- ° Programmable remote units

It is emphasized that the processing capability (computer speed, memory expansion, word size, and instruction set) of the micro processor used in this equipment is as important to the DACS as is the processing capability of the Computer Subsystem to the Energy Control Center. This is particularly true in the PTU where there is the capability for expansion of functions. This expansion capability is predicated on the availability of unused storage and processing capability.

a. Communications Interface Unit

The Communications Interface Unit (CIU) is the interface between the computer subsystem and the communications channels to the Programmable Remote Terminal Units (PTU's) and other computers.

Typically, the CIU must perform the following functions:

- ° Interface to multiple host computers
- ° Buffer data to/from channel adapters
- ° Transfer data between host computers

- Provide switching of redundant communications lines

- Detect errors in transmission by use of parity, checksums, cyclic error coding, or other technique

The channel adapters used by the CIU must support the interface to several types of remote devices. This includes other computer control centers and remote consoles, as well as RTU/PTU's.

b. Programmable Remote Terminal Unit

The Programmable Remote Terminal Unit (PTU) provides the interface to field device sensors and control devices. Typically the PTU will perform the following functions:

- Support communications line protocol and message formats

- Maintain a local data base of current state of all field devices

- Receive and analyze requests from the control center

- Format return data

- Execute special functions, e.g. relay controls

- Support different data types:

Discrete Input	-momentary status -change detect status -latching status -pulse counters
Analog Input	-single ended input -differential input
Control Output	-momentary control -pulse duration
Analog Output	-set points

- Provide other optional capabilities:
  status report by exception
  analog freeze
  sequence of events

The PTU must provide for security of operations. This requirement includes automatic recovery from power cycling and IEEE surge withstand capability. Various function checks or reference quantity tests may be used to provide warning of failed or degraded operation.

Many state-of-the-art remotes are programmable. This means that a mini computer or micro processor is used instead of hardware logic. The programmable units offer many advantages over the non-programmable types: cost/performance improvements, reduced number of different hardware components (e.g. printed circuit cards), improved diagnostic capabilities, and others. Most important, they provide capability for local processing and control. The pendulum of the economic pay off equation is swinging rapidly toward more local processing applications. Caution must be exercised however, to insure that the unit's programmability does not compromise its security of operation. This is particularly true for field programmable units. The potential future application for programmable remotes includes:

- Sequence of Events Recording
- Closed Loop Control
- Local Data Collection and Logging
- Equipment Maintenance Recording
- Load Management
- Calculation of Parameters (instead of instrumentation)
- Local Operations

The capabilites of the micro processor are key to the ability of a PTU to incorporate these additional functions. In some designs programmability means only the capability to change message formats through firmware, with no ability to handle the new applications. The PTU should be selected or designed with the full range of potential applications in mind.

c. Communications Media

The range of options available in the communications portion of the DACS is such that only a summary of the more frequently used techniques will be presented. From the standpoint of the DACS there are just a few characteristics that are pertinent. Generally, all communications interfaces should comply with EIA Standard RS232C. Communications used for these applications are generally dedicated, full period lines as opposed to dial-up type circuits.

Aside from the quantity of the communications circuit, the DACS will have requirements for bandwidth adequate to support the desired data transmission bit rates. These bit rates are determined by the required data scan rates, volume of data, and numbers of PTU's per circuit (party-lined). Typical utility applications use 1200 BPS circuits for interface to RTU's. Interfaces to other computer centers range from 1200 to 9600 BPS. Remote consoles, with requirements for frequent display update of fast response for display requests, may require from 9600 BPS up to 40.8 kBPS communications.

The communications media are typically one or more of the following types:

- Voice-grade land line
- Micro-wave
- Power line carrier
- Radio

REA Bulletins 66-4 through 66-8 cover these media in detail.
A single circuit may be composed of only one type or may be a combination of two or more types with suitable interfaces. Multiple circuits may be used to connect remote units to the Energy Control Center. In such designs, appropriate switching must be provided at both the control center and at the remote unit. This switching may be by operation of hardware and/or software.

A new technology that is developing rapidly is that of fiber optics. It appears to offer excellent immunity to the normal sources of electromagnetic interference. It will probably have its first

application in power plants or for local substation control where relatively short dedicated lines can be used.

d. Message Standards

Message standards for communications between the energy control center computers and Remote Terminal Units and other computers are usually unique to each Vendors equipment. An understanding of the significance of these standards is important to properly evaluate many areas of system performance and expansion capability. In some cases the message standard is a reflection of hardware limitations. However, the message standards may sometimes impose more restrictive limits on the capabilities of the Data Acquisition Subsystem. This may be due to the message standard itself or to restrictions imposed by the Data Acquisition Software/Firmware. The significant characteristics of any message standard include security, efficienct, addressing capability, and compatibility with other standards.

The security of the message standard is by far the most important. Several coding schemes have been used to provide transmission security. These include checksums, horizontal and longitudinal parity bits per character, Bose-Chaudhuri-Hocquenghen (BCH) code, and others. Transmission errors are to be expected, with errors occurring at typical rates ranging from 1 in 10^5 to 1 in 10^3 bits under normal operations. Even though the Data Acquisition System may transfer data at a low rate, the detection of these errors is an absolute requirement. No scheme will provide 100% error detection under all noise conditions, so it is prudent to carefully evaluate the hardware and software for adequate error checking.

Transmission efficiency is of interest and sometimes becomes a critical factor even in a properly designed system. In selecting the number and speed of communication links, transmission efficiency, error rate and message retry philosophy must be considered.

Addressing capability is important in that it may limit the expansion of the subsystem either in the number of PTU's (total or per channel) or in the number of points within a PTU. This is due to the field size (number of bits) allowed for terminal (station) and point addresses.

Compatibility with other standards may be important when adding remote terminals to existing Data Acquisition Subsystems. In the past, add-on RTU's were almost always sole source items to the original supplier. However, with the programmable nature of present equipment, many Vendors can supply add-on equipment using any message standard.

As has been stated, there is significant variation in message standards used by different Vendors. In recognition of this, the subsystem designer should specify his minimum requirements as related to the message standards and not unnecessarily specify the message formats. Message standards should be specified only for existing equipment that will be used in the new Data Acquisition Subsystem.

5. Software Features

While the hardware elements provide the needed electrical interface to acquire and route remote data, it is the software (firmware) that provides the intelligence of the Data Acquisition Subsystem. The software defines what data is to be acquired, scan/poll intervals, data base structure, processing of received data, expansion dapabilities, and user interfaces to the data base. The operation of the Data Acquisition Subsystem has few external manifestations that are apparent to the control center operations personnel as to the Man/Machine Subsystem and the Applications Software. However, the DACS is fundamental to the propoer operation of the entire energy control center. The major functions of the Data Acquisition Subsystem Software are discussed in the following subsections. The Data Base is discussed first as the focal point for the entire subsystem. It is the digitized image of the electric power system.

a. Data Base

The data base (and its structure) is of significance to the system designer, as it determines a number of key design parameters. It is a major component of

computer storage requirements (core and auxiliary) and it will impact execution times of other software as a result of the overhead associated with data base access. The data base may provide a single unified data base for remote (scanned) data, and for applications (calculated) data, or they may be totally separate.

The data base for remotely acquired data must include not only the current status/value of each point, but must also include certain data/flags regarding the quality of the data or operational state of the point. The requirements in this area are highly dependent on applications and operational (operator) requirements. The typical data items in the data base for the various types of acquired points are as follows:

- Status/Indication Points - Current Status
Normal Status

- Analog Points - Current Value
Scale/Bias Factors
High Limit(s)
Low Limit(s)
Rate of Change Limit(s)

- Accumulators - Value for Current Interval
Current Reading
Rollover Constant
Scale Factor
Data Format

The data base may include pointers to other system tables to support operation of the software. Also included in the data base for each point will be a set of flags which define the quality of the data or the power system condition represented by the data point. These flags may apply to one or more of the point types:

- Deactivated Flag - The data base for the point is not to be updated even if valid scan data is received

- Telemetry Error Flag - The data base for the point was not updated on the last scan due to some type of telemetry error

- Manual Data Flag - The operator has over-ridden the scan and substituted and operator entered value.

- Point Selected Flag - The point is currently selected by the operator for some function

- Alarm Flag - The point is in an alarm state

- Acknowledged Flag - The existing alarm condition has been acknowledged by the operator

- Change Authorized Flag - A change in the status/ value of the point is expected and should not be alarmed

- Tagging Flag(s) - The operator has applied a tag or tags to the point to inhibit control of other functions

This list of items in the data base is not all inclusive. Particular applications may cause unique requirements for the data base. In all cases, it is important to clearly specify requirements for functions that depend on the existence of certain information in the data base.

The particular layout of the data base has significance to system performance due to the overhead that may exist for access to the data base. In many system designs, access to the data base is through a single set of interface software called the data base manager. There are many valid reasons for this approach:

- Allows virtual data base; makes users independent of allocation of the data base to different storage types.

- Can provide higher degree of security against unauthorized change to data base

- Simplifies expansion capabilities

- Allows collection of usage statistics for tuning performance of the system

- Reduces impact of reaching limits of core memory expansion

Whether a virtual data base approach is used or not, satisfaction of the basic requirement is dependent on many parts of the data base being core-resident. Frequency of access and required response time for display call-up, data acquisition scan cycles, as well as the application functions, will determine the allocation of storage to the data base. Usually, the entire data base for remote (scanned) data will be core resident to satisfy these requirements.

b. Data Acquisition

The Data Acquisition Software supports message exchange sequences for all scan modes, generates the necessary commands for information required, performs error checking to assure the validity of data and the proper completion of scan requests, and updates and maintains the data base. In addition, the Data Acquisition Software provides support for the supervisory control functions by transmitting commands, timing-out the operation, and performing error checks.

Data may be received on a cyclic basis or by exception The Data Acquisition Software must allow for multiple cyclic scans, each having assigned priority and interval between scans. For each such scan, the software must format the appropriate data request, transmit the request, and check the return transmission for errors.

All valid received data is then subjected to processing according to the data type. The received data and any associated derived quality data is entered into the data base. Typical processing requirements are primarily oriented to detection of alarm conditions, which is discussed in a later section. Other processing of data might include conversion of analog data to engineering units, and calculation of time interval (hourly) values for accumulator points.

Performing the complete Data Acquisition Function for all remote points on a fixed cyclic basis can overload the computer system and/or the communications channels and may cause unacceptable time skew in the received data. This possibility is important because, in many systems, communications represent the largest single cost element. In order to minimize communications channel bandwidth requirements, a Report by Exception scheme is frequently utilized.

Other approaches, such as quiescent remotes, have been used. Quiescent remotes transmit device status to the control center computers on a change or interrupt basis. Since these transmissions are not controlled by a single master, the potential exists for simultaneous transmissions by multiple remotes on the same communications circuit. Special software is usually required for some situations, such as turning off all remotes, then turning them back on, one at a time. For that reason, and others, the Report by Exception Approach seems to be favored by most of the industry.

c. Report by Exception

In the Report by Exception Approach, a polling technique, is used instead of, or in combination with, the scan approach. This technique typically includes the following steps:

- The Data Acquisition Software sends a poll to each PTU at periodic intervals

- The PTU responds to the poll with a report that data has (or has not) changed

- The Data Acquisition Software must then issue a scan request to acquire changed data

This approach is particularly advantageous when there are large numbers of status points which change state only infrequently. Reporting by exception can also be applied to analog points by use of a change threshold. For example, the threshold could be defined as a change in the third (or higher) least significant bit since last reported change for this point. This represents only 0.1% of the range for the 12 bit value, which is less than the combined accuracy of sensors and conversion equipment.

There is a shortcoming of Report by Exception, however. While it does greatly reduce the communications loading under most conditions, it can present heavier loading than the scan technique under conditions of frequent and continuing change. This is due to the fact that the Report by Exception approach requires additional overhead in the message structure for point identification. Also, if points change rapidly and continually, they may be scanned more frequently

than they would have been scanned under periodic scan approach. It is important to understand the conditions under which the communications system becomes saturated and the impact this might have on the operation of the Energy Control Center.

This shortcoming of Report by Exception manifests itself when it is least desired, i.e. during system disturbances. In some systems it may even be self-defeating due to this anomaly. Careful and prudent design is essential. A hybrid design approach that could alleviate this problem, is one where in the high rate of change and memory status points are periodically scanned, while slow rate of change status points are reported by exception.

d. Error Detection

It is imperative that the Data Acquisition Software prevent invalid data from entering the data base. All received data must be checked for errors. The following categories of errors may be detectable:

- Channel adapter and PTU hardware detected errors

- Communications interface hardware detected errors
  - Timeout
  - Transmission errors
  - Inoperative
  - Data transfer errors

- Software detected errors
  - No response
  - Data overrun/underrun
  - Data identification errors

The specific errors in each category, to a large extent, are dependent on hardware design. It is important that all available error indications be utilized and that the basic requirement is satisfied that no invalid data enter the data base.

Some form of error statistics, e.g. daily error count by error type, should be maintained to aid in diagnostic and corrective action. In addition, a short term error rate may be the basis for alarming marginal operation or failure of equipment.

e. Alarm Detection

One of the more important functions of the Data Acquisition Subsystem is that of the alarm detection. Normally, all scanned data is subjected to some type of check to determine whether a point should be alarmed to the operator. The following types of checks are typical:

- Status Change - Status/indication point has changed state since last scan. An unauthorized change alarm should be issued unless the change was authorized, in which case a completion of operation message should be issued. Change detection may include distinction of single and multiple changes of state betwen scans

- Limit Checks - Analog values may be tested against one or more sets of limits. Alarms are generated if limits are exceeded. Sets of limits may be provided for operational, emergency, or other conditions

- A specified number of alarms must be CRT displayable in one or more alarm list displays. Procedures for overflow of the lists must be defined

- Alarms which occur during a time window immediately preceding a failover may be lost. Systems have been implemented with this time window as small as 100 milliseconds. In most systems, that requirement can be relaxed somewhat since the first scan after failover would "re-detect" the "lost" alarms if they still existed

f. Supervisory Control

The Supervisory Control Software Functions are typically thought of as a man/machine function, however, the Data Acquisition Software usually will have the responsibility for actual communications with the PTU where the control is to be actuated. This software must support several functions and modes of operation. The primary responsibilities are the formatting of the control messages, transmission of the messages, and validation of the checkback according to the defined message protocol.

Both immediate operate, and select-then-operate modes are used. The immediate operate mode is used for repetitive type operations where communications time must be minimized. Typically, generation control applications will use the immediate operate mode.

The select-then-operate mode is used for operator supervisory control functions. This mode requires a select message to the PTU, and a final checkback response.

The security of the control operation provided by the combined functioning of the Data Acquisition Hardware and Software is of paramount importance. No error or failure mode should allow unauthorized operation of a control relay.

g. Failover Considerations

The Data Acquisition Software, together with the other software subsystems, must make provision for failover to the backup system in case of critical failure to the system operating in the primary mode. Typically, this will entail:

- Transfer of the data base to the alternate system at intervals, usually 30 seconds

- Transfer of Subsystem expansion updates after validation

- Re-initialization after failover
  - Restore data base to the last snapshot
  - Restart all scans
  - Abort or restart control sequences that were in progress

Data base snapshots may also be placed on the primary system's disc to allow for primary system restart after critical failure, when the backup system is not available.

h. Subsystem Expansion

The Data Acquisition Subsystem must be capable of easy expansion as the power system itself expands. This expansion is by growth in point count in existing remotes, by the addition of new remotes, and by addition of new functions (e.g. sequence of events) in

existing remotes. It should not be necessary to take the system off-line to perform this expansion. The system should be capable of fast restoration of a prior system in the event that the expanded system is defective. Security checks should be provided to detect erroneous inputs, and to prevent their entry into the data base.

Many different techniques have been used for this function and several are basically acceptable. The two basic approaches are source data cards and CRT interactive input techniques. The preferred approach is the latter, as it eliminates the problem of card handling, provides for timely error collection, and, in the better designs, provides step-by-step input instructions. With the CRT approach it is imperative that the system provide capability for a test data base and a saved data base. These capabilities allow for suitable backup for restoring the system after hardware failure.

A capability of dual or parallel primary is quite useful for checkout of subsystem expansion. The dual primary mode of operation is one wherein the backup CPU is assigned only the equipment to be tested, and possibly a console. The Backup CPU then acts as if it were in the primary mode, executing all primary software functions, but having access only to the equipment under the test. This allows for a fully integrated checkout of the expanded data base, software changes (if any), and the new hardware.

i. <u>System Performance Analysis</u>

Proper design and implementation of a Data Acquisition Subsystem requires a number of analytical studies to validate that the proposed approach does satisfy all system performance goals. Many trade-offs are possible. The following briefly summarizes several of the more important analyses that should be performed:

° Communications Timing Analysis - Can communications support all periodic scan cycles and random events such as report by exception, sequence of events, supervisory controls, noisy communications, etc?

- Computer Subsystem Storage Requirements - Size of the computer core storage and auxiliary memory required to support the Date Acquisition Subsystem

- Computer Subsystem CPU Time Utilization - Is CPU utilization by Data Acquisition Subsystem consistent with system design?

- Auxiliary Memory Utilization - This analysis is important when the major parts of the real-time data base and of the Data Acquisition Software reside in Auxiliary Memory. Is the Auxiliary Memory utilization consistent with the system design?

- Response Time - This study defines the ability to maintain scan rates, to detect alarms within a reasonable time after their occurrence in the field, and to provide data to Applications Software having an acceptable time skew.

In addition, if the remote terminal units are programmable, it may be necessary to perform Computer Subsystem Storage Requirements, Computer Subsystem CPU Time Utilization, and Response Time Studies for the PTU's also.

To begin such an analysis, it is necessary to collect data such as PTU point counts, scan cycles, characteristics of the Data Acquisition Software. Also, timelines or scenarios must be defined that are to represent system operation. This is a critical aspect of the analysis, as a non-representative timeline will cause the study results to be non-relevent. It is important to analyze several timelines:

- Normal loading (over a long interval, e.g. 30 minutes)

- Heavy loading (over a short interval, e.g. 30 seconds)

- Worst case loading

The heavy loading period over a shorter interval should place emphasis on demand type events. The worst case loading situation is always of concern to assure that system operation remains acceptable.

The analysis should reveal any instances of under/ over design. Certain trade-offs are available to correct designs that results in unacceptable performance. First of all, the basic data, sizing, and timelines, should be examined to re-evaluate their representativeness. If the problems persist, then changes to the system design must be considered. While it is not possible to give explicit solutions to undefined system problems, the solutions to be considered may include one or more of the following:

° Use faster communications media

° Scan the PTU's less frequently

° Use multiple scan cycles to effectively reduce scan rate

° Use polling/Report by Exception techniques. This is most frequently used for status points only, but could also be applied to analog points

° Reduce extent of party-lining of PTU's. This allows more parallel communications, but may incur substantial communications costs

° Distribute processing with intelligent (programmable) PTUs

° Expand the Computer Subsystem

° Add "Front End" Processor

Quite frequently conflicting requirements occur where the utility desires to party-line many remotes due to the radial nature of their system and the cost of communications circuits. This conflict occurs because of the various data acquisition cycles; the generation control function (normally at 2 second intervals), the study programs (normally at 10-30 second intervals, but time skew of data is critical), and the normal dispatcher SCADA functions of monitoring, logging, and supervisory control. Such a conflicting situation existed on a system in development at TRW. The resultant solution involved use of Report by Exception for status points, and an "analog freeze" capability to snapshot analog values at all PTUs, with one universal command followed by transmission of the analog data back to the control center, over a 20 second interval.

j. Other Considerations

Other aspects of the DACS must be given consideration as part of the design process. These include the testability, maintainability, spare parts inventory, and training requirements, among others.

Diagnostic capabilities are very important, particularly with programmable devices. Diagnostic testing tools may be software or hardware, integral with online DACS, or stand-alone. These diagnostic tools, together with the error detection/reporting capability of the hardware, will significantly impact time-to-repair, which in part, determines the availability of the subsystem. Programmable units typically are provided with several types of diagnostic capabilities:

- In-plant microprocessor based diagnostic systems are used for board test and automated testing of end items, such as PTUs and CIUs

- A portable maintenance panel is a field diagnostic device which provides capabilities such as display to all registers, address stop, single step, single cycle, and others

- Portable analyzer units can emulate a PTU or CIU and can provide for display of received data, for operator definition of transmitted data, for selected error checking, and for simulation of error conditions

- Firmware/software diagnostic can check:
  - Basic harware interfaces
  - Complete instruction set
  - Memory
  - All I/O cards - channel adapters, discrete input, analog input, accumulator input, control output, analog output, and discrete outputs

The commonality of the hardware is also to be given consideration. The numbers of different printed circuit card types used will impact training, spares requirements, and system maintenance/availability. For example, typical equipment configurations will have common basic structures for the CIU, PTU, and man/machine equipment. Only the I/O cards vary. Even there, the multiplicity of card types could be

reduced. For example, a single discrete input card with appropriate firmware can support either momentary status, change detect status, latching status, and pulse count accumulation.

Maintenance philosophy for both hardware and software should be defined early in the project cycle. If the Borrower desires to perform its own maintenance, staffing and training of the personnel should be planned. Consideration should be given to their participation in development of the system at the Vendor's facility. Usually this approach provides the benefits of more complete in-plant testing, easier transition during field start up of the system, and shortened down times due to hardware/software failures.

III. DESIGN CONSIDERATIONS AND CONSTRAINTS

A. System Functions

The functions contingent to the planning for the establishment of an Energy Control System (ECS) are covered in this section. The functions are based on an evaluation of "across-the-board" long range requirements determined via discussions between engineering and system operating personnel, and are consistent with standard equipment offerings of control equipment manufacturers. The functions given here are judged to be important to system operations, and can be both economically justified and easily implemented in the control system.

For economic and efficiency reasons, not all of the functions listed need to be purchased for the initial system. Some can be added at installation time or at some time in the future. Any vendor should be required to provide a system capable of performing all of these functions, even though complete system hardware may not be initially purchased. Designation of the vendor or the borrower, as a supplier of a particular functional program should be done in the system specification stage. During the specification stage, selected functions should be described in qualitive and numerical detail to aid the vendor in supplying a system which will satisfactorily perform them. After vendor proposals have been received and reviewed, a final decision of programming responsibility should be made.

A few of the functions discussed are sufficiently advanced, or may be particularly unique to the selected operating philosophies. These functions are described herein as optional. Separate pricing for them should be solicited in specifications so that their cost effectiveness can be judged.

1. Automatic Generation Control

An AGC program should provide for the regulation of the net power output of generators in response to changes in system frequency, tie line loading, or the relation of these to each other, so as to maintain the scheduled system frequency or the established net interchange with other companies within predetermined limits. The program should include provisions for the control of the required number of dispatch units, operate at a programmer or engineer adjustable timing in the range from one to ten seconds, and provide for digital, non-linear filtering of the calculated Area Control Error (ACE).

The AGC program should distribute control signals to units under control to satisfy the system regulating obligation in proportion to regulating participation factors entered by the System Dispatcher. Economic distribution of generation would also be maintained by moving units in relation to base points and participation factors produced by the Economic Dispatch calculation. The AGC will operate in either a permissive or command mode depending upon the level of ACE and control status of units. An emergency assist mode will be entered automatically if ACE exceeds a predetermined MW level or upon operator action. A variety of unit control modes should be available for selection by the System Dispatcher to allow individual units to be on or off control, to participate in regulation or economic dispatch, or to be manually controlled and base loaded. Unit output should be constantly compared to system dispatcher entered generation and rate limits and unit output maintained within these limits.

2. Economic Dispatch (ED)

Tools should be provided to assist the System Dispatcher in producing base points and participation factors to cause the AGC programs to economically distribute total required generation among units on line. As a minimum, a capability should be available to display unit incremental cost data to allow System Dispatchers to select economic operating points.

Since the complexity of any task will increase substantially when future generating units at remote sites are installed, consideration should be given to a more sophisticated, automatic ED calculation. This program should optimize the incremental cost of power delivered by considering unit incremental cost curves and manually entered transmission penalty factors. The ED should be performed periodically of upon the occurence of one of the following events: significant change in in system load, change in the status of any dispatch unit, or dispatch request. Criteria controlling the running of the ED and its data parameters should be under system dispatcher control. The ED program should reflect cost curves with polynomial coefficients, or multiple straight line segments, and should have the capability for dispatching both controlled and non-controlled generators.

3. Interchange Scheduling

The interchange scheduling program should provide time-scheduled power flow information based on a library of prescheduled transaction. The output of the interchange scheduling program would be used by the AGC program. The library should contain three categories of transactions: (1) transactions previously scheduled and timed out (last 24 hours only); (2) transactions presently in progress; and (3) transactions scheduled for the future. The program should determine the desired instantaneous net interchange and ramp for those transactions in the second category. The program should also provide running totals for various types of schedules, plus associated costs to be used for monthly billings. Inadvertent interchange balances should also be maintained.

The program should include the capability for the System Dispatcher to add new transactions to the library to begin immediately or at any time within the next 24 hours. All system dispatcher entries and deletions from the schedule should be logged. A message indicating an impending transaction should be presented to the system dispatcher five minutes before the start of the transaction. The instantaneous tie line flows at the beginning and end of each scheduled interchange transaction should be logged.

The System Dispatcher should have the capability of entering transactions with several interconnected companies, with at least eight different transaction types (e.g., emergency, replacement, economy or surplus). The program would apply programmer or engineer changeable cost factors to these transactions, or where appropriate, except cost data from the system dispatchers. Transmission loss factors assessed by the utilities should be automatically applied to each transaction in keeping with programmer or engineer entered contractual provisions. The System Dispatcher should have the capability to modify any of these factors. The program should display both the nominal value of each interchange, and the actual value corrected for transmission loss requirements.

The Borrower may be required to supply energy to the interconnected utilities to offset their transmission losses in moving power from the generation facility to its load. The Interchange Scheduling Program

should automatically calculate these transmission loss requirements for each group or load, and synthesize corresponding scheduled interchanges. This calculation should be performed periodically, at a rate adjustable by the programmer or engineer, in the range from one minute to one hour. The total load including transmission loss requirement for each of the interconnected utilities shall be available for real-time transmission to the individual utility control centers.

4. Supervisory Control and Data Acquisition

System Dispatchers, who are responsible for system control and security, require a comprehensive, quantitive representation of the power system. Data should be telemetered digitally from generating plants, substations, and bulk delivery or metering points, at the various rates necessary for satisfactory performance of all system functions. Status data should be scanned at high rates (every two seconds). Generation, tie line, and metering point flows, should also be telemetered every two seconds to provide timely inputs to the AGC program. Less critical data should be scanned at longer intervals (every ten or thirty seconds, or one hour for MWH and MVARH metering) to provide system monitoring of the complete system and updated information to other functions.

The new system should provide the system dispatchers with the capability to select and control remote devices such as breakers and motor operated disconnects. Control actions would be accomplished via a CRT display exhibiting the device to be actuated. Inadvertent operation of devices would be prevented by requiring a system dispatcher to verify his selection of a particular device before control action can take place. The system would automatically confirm the accuracy of the selection at the remote site and verify correct operation of the device by subsequent scanning of its status. The new system should automatically log all control actions executed by the system dispatchers in a chronological log. The types of supervisory control to by provided are described below.

a. On/Off Control

On/Off devices include breakers, disconnect switches, reclosing relays, and underfrequency relays. The new system should report the status of all two-state devices, including high-speed reclosing breakers, recognize the different response times of various

devices, and provide the System Dispatcher with an indication that a control action is in progress or has been completed. The initial system should be capable of controlling all on/off points to be incorporated during the life of the computer system. On/off control includes control and indication points describing the present state and operation of automatic equipment at remote locations. Memory should be provided at RTUs to indicate any operation of the equipment occurring between scans.

Controllable devices will be provided with a Local Remote Blocking Switch on the substation switchboards, to prevent operation when maintenance is being performed. The status of each of these switches should be telemetered and displayed to the System Dispatcher and the software should prevent any attempt to control blocked devices.

b. <u>Control of Tap Changing Transformers</u>

The ECS should monitor and provide for system dispatcher control of tap changing transformers. Each transformer is controlled by two sets of contacts: (1) Automatic/Manual (mode control), (2) Raise/Lower (action control). Automatic control refers to a local automatic control loop at the substation. If the transformer in question is in the automatic mode, a system dispatcher would first change the control mode to manual. Once the transformer is in manual control mode, a System Dispatcher could raise and lower the tap position which would be continuously displayed to him. When control action is initiated, the software should monitor the tap position to ensure that the desired action has been accomplished. A message indicating either successful or unsuccessful control action should be recorded for each control action attempted. Any attempt to initiate a raise/lower control action to a transformer in the automatic mode shall generate an error message. In some cases, two or more transformers should be operated as a unit. These sets of transformers have a common Auto/Manual control and indication point. If the transformers are in Auto, the local control element keeps the transformers within one tap position of each other. In Manual mode a System Dispatcher should have the option of stepping the transformers simultaneously (for paralled banks in station) or independently. The computer will monitor the tap position of each

transformer in a paralleled group and initiate an alarm whenever they are more than one tap position apart.

5. Data Processing

The ECS should perform routine data processing on all telemetered variables. Each value would be converted to engineering units, tested for reasonablity and checked against dispatcher enterable upper and lower limits. The computer system should have the capability for creating calculated variables which are formed by using programmer or engineer specified algorithms, involving one or more telemetered values. These calculated variables would become a part of the data base and be treated by all other software programs as though they were remotely acquired variables. Both continuous and discreet calculated variables should be provided. Defining algorithms might consist of standard functions such as sums, differences, averages, integrations, minimal, or special calculations. The following special calculations should be provided initially in the ECS.

a. Meter Error Analysis

Data from tie lines and metering points is collected in two forms: instantaneous MW readings approximately every two seconds, and MWH data collected every hour. Control is based on the two second MW readings. Integration of these readings over an hourly period should provide the same value as collected via the more accurate MWH digital telemetering. The Meter Error Analysis program will monitor the readings for integration discrepancies and advise the System Dispatcher of the immediate correction that should be made to reduce erroneous interchange. All metering errors should be logged for use by maintenance personnel.

b. MVA Calculation

MW and MVAR data will be telemetered for transformers, and some transmission lines. The computer should calculate the MVA flowing on these devices and check the results against limits to determine overloads.

6. Data Logging

The ECS should generate as many of the required formal

logs as possible. Data on the log sheets may be telemetered, calculated, or entered manually by a System Dispatcher. Logs should print their own column and row headings, and not require preprinted log forms. The data base should be used to supply complete and accurate historical logs for use by other departments. The ECS should provide a separate facility for logging status, change-in-status, alarms and other data. The system should also provide a hardcopy log on the alarm/events printer of all system dispatcher control actions, limit changes, and breaker tagging operations. This hardcopy chronological history would provide a historical record useful in verifying and re-evaluating optimum operating practices. Certain logs would occur hourly, others, once per shift, or daily. The System Dispatcher may request the printing of any periodic log. The contents of any CRT display may be logged upon System Dispatcher demand.

7. Load Management

This function would provide the System Dispatcher with a CRT display of the schedule of loads to be interrupted when an emergency arises. A CRT display will provide the interface through which the System Dispatcher may quickly initiate the load interruption sequence. Load interruption points may be multiple breakers, with points within a set existing at separate RTUs.

As an option, the load shedding program may maintain a record of all actual load interruptions so that they may be accomplished on an equitable basis. During a load interruption period, the program would keep track of outage times and alert the System Dispatcher when it is time to transfer load interruption to the next scheduled group. Restoration of service to disconnected loads will be done on an individual circuit basis, using the standard supervisory control functions.

8. System Peak Analysis

Periodically, this program should calculate the instantaneous and hourly system loads. As new peaks are achieved, the magnitude of the peaks and associated readings should be retained in long-term historical storage. The current daily peak to date should be available upon system dispatcher demand. The values retained/logged at each peak and the retention period for the storage buffers should be under programmer or engineer control. Separate peak analyses should be performed for the total system load,

and for those portions of the load distributed to other interconnected utilities. To aid in billing of member cooperatives, the peak hourly load in a calendar month, for each metering point, should be determined and retained for an adjustable period.

9. Energy Accounting

The telemetering of data from all significant loads is necessary to meet generation control obligation. The hourly MWH and MVARH data is collected from these locations can also be used to support a variety of accounting functions, specifically:

- Daily energy logs: At the end of each day a 24 hour log should be prepared showing hourly and total energy usage and interchanges for each member cooperative and utility. A system dispatcher should have the opportunity to review and edit the log to account for known telemetry errors and to supply data for non-telemetered loads

- Weekly energy logs: At the end of each week a seven day log should be produced showing hourly and total energy usage and interchanges for each member cooperative and utility. A system dispatcher should have the opportunity to review and edit the log to account for known telemetry errors and to supply data for non-telemetered loads. The log will be used to conduct weekly metering checks where required by contract

- Monthly energy accounts: Each month, the hourly MWH readings for each metering point for the month should be output. Totals for each metering point and the peak MWH, corresponding MVARH and peak MVARH should also be provided. Output of this data should be printed in form and on a machine readable medium such as magnetic tape for possible processing by an accountable computer

- Monthly interchange summary: Tabulations are required of all interchanges by type each month with each interconnected utility. Inadvertent interchange balances should also be shown for the current and previous months

10. Disturbance Analysis

The analysis of a system disturbance should be segmented into three distinct periods: predisturbance, disturbance, and postdisturbance. The start of a disturbance should be indicated by an absolute value of frequency, a rate-of-change of frequency, a prespecified value of ACE and/or net interchange duration, of by preset changes in configuration. The disturbance should be declared over upon restoration to normal system operating values. All events denoting the beginning and ending of a disturbance should be under programmer/engineer control. During the three periods of disturbance, system frequency, load and net interchange, unit real and reactive power, real power flow on selected lines and transformers, and selected bus voltages should be collected. The program should be structured to allow other items specified by the programmer or engineer to be collected. Software programs should be provided to analyze the mass of data collected, and present well organized displays of data to the engineer. This should include graphic displays on CRTs, strip chart recorders, and hard-copy logs. The ultimate goal of the disturbance analysis package should be to provide sufficient information on previous disturbances to enable early warning and prevention of future disturbances.

11. Storage and Retrieval

A storage and retrieval program should periodically collect and store data as specified by the programmer or engineer. Data may be telemetered on calculated values, and should be retained in circulating buffers in auxiliary memory for prespecified time periods (minimum of 30 hours). The retention period for each buffer should be independently specified. The programmer of engineer should have the capability to periodically dump the buffers to magnetic tape for long term retention of the data. Associated programs should be available to format and display these variables periodically, at a specified time after an event, or upon dispatcher demand. Display facilities should include logging, pen recording, and CRT displays. The program structure should be modular and allow for other programs of this type to be added at a later date. One program for retrieval of this data has been identified and should be investigated as an option in the specification. Hourly load data could be retrieved from this file for delivery points. This data could be automatically supplied (at the system dispatcher's

discretion) to the AGC program as a substitute for failed telemetry data for affected metering points.

12. Background Facilities

State-of-the-art hardware and software facilities should be provided for the programmer or engineer responsible for maintaining and augmenting the system. Provisions should be made for the programmer or engineer to assemble or compile programs utilizing the full capabilities of the CRT. The programmer or engineer should utilize the CRT to debug new programs without interfering with or endangering the normal on-line functions of the system. The programmer or engineer should be capable of utilizing his man/machine interface to integrate new programs into the system on-line. The system should include assemblers or compilers for all languages used by the vendor for original system sofrware, plus diagnostic testing, and exercising programs to periodically examine the status of as many peripherals as is practicable, without interfering with the normal operation of the system. Provisions should be included for the creation of new CRT displays and logs and for the editing of existing formats.

13. Dispatcher's Power Flow

A transmission system may be run at near capacity levels. As the transmission network becomes more complex, it will be increasingly difficult for a system dispatcher to determine beforehand the results of various switching operations. The dispatchers need to know this type of information, however, so they do not perform switching that jeopardizes the integrity of the system. This dispatch function can prevent overloads, possibly even prevent service interrruptions, and certainly makes the dispatcher's job easier. The use of a power flow program at an off-line console as a training device for new dispatchers will provide significant savings in training time and dollars over a very short period.

14. Load Forecasting

Accurate forecasting of electrical demand is the first step in scheduling generation interchange. This information is critical to the generation scheduling in order to provide the smoothest, most economical transitions between daily peak and low demand periods. The weather has a major effect on any system load and must be

accounted for in any load forecast programs considered.

15. Control Center Layout

Figure III-1 shows a typical layout of an ECS control center. The ECS operators use man/machine devices to interface with and operate the generation-transmission system and distribution system. Major elements which make up the ECS man/machine subsystem may include:

- Power console
- Transmission console
- Programmer's console
- Logging printers
- Line printers
- Magnetic tape units
- Video hard copy device
- Card reader
- Static mapboard
- Chart recorders
- Time frequency and digital display panel
- ECS status and configuration panel

a. Consoles

Two control consoles may be provided. A transmission console, and a power (generation) console, each so designed that the ECS can be fully operated from either. Each position should be equipped with seven-color CRT display monitors, alphanumeric and special function keyboards, and a light pen. Space shall be provided for radio and communications turrets on each console. Details of consoles and communications will be coordinated with the Borrower following Vendor selection.

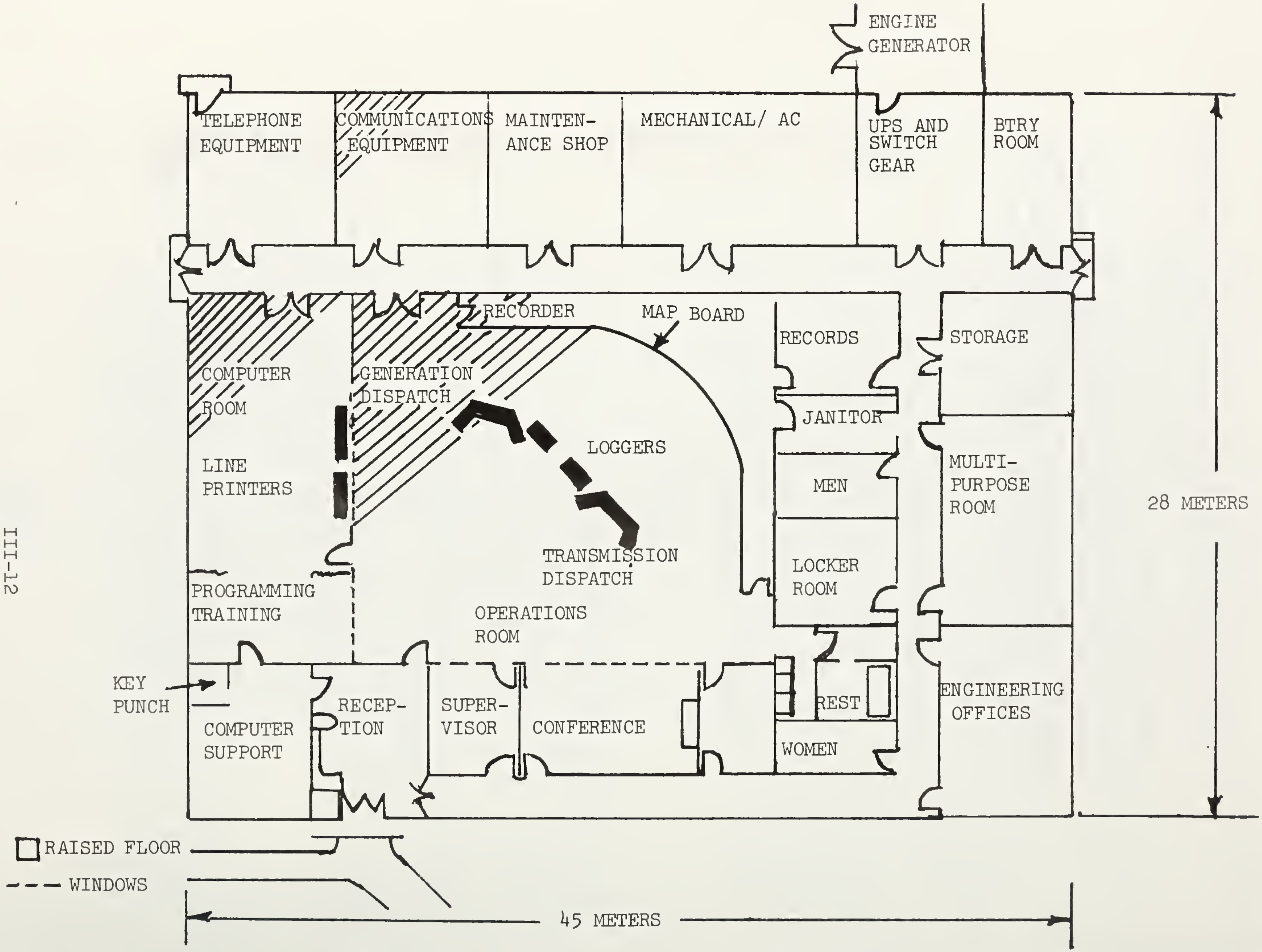


Figure III-1 Conceptual Control Center Space Layout

The power console should provide the required facilities for the system operator to monitor and control programs and functions associated with the generation. The console will normally be used for modification and insertion of control parameters, substitution of missing data, manual execution of programs, monitoring of generating facilities, requesting logs and reports, and initiating selected programs including load scheduling functions. This console may also be used for other general-purpose dispatch functions.

The transmission console should provide the required facilities for the system operator to monitor and control the bulk transmission network. The console will normally be used for general system monitoring, supervisory control, and equipment tagging and related orders on maintenance and emergency outage dispatching. This console may also be used for other general purpose dispatch functions.

A single position programmer's console may also be provided. The console should have a seven color CRT display monitor, an alphanumeric keyboard, a special function keyboard, and a light pen.

The programmer's console should provide the capability for generation and modification of CRT images, for modifications to the system data base, for program developmemt, and possibly for operator training. This console shall have the capability of being independently switched between the on-line processor and the backup processor. The programmer's console should interlocked with software such that no control action or replacement of real-time data may occur from this position. Secure provisions shall be provided to unlock this console in the event it is required for emergency operations. This shouldbe accomplished through the use of a software key which would make this console available to support system operations. In this event it shall be made unavailable to programming functions.

b. Logging Printers

Logging printers should be provided which are centrally located with respect to the power and transmission consoles such that they can be easily viewed from either operating position. One unit will normally be utilized for alarm logging and one for operator action

logging. A third logger will be located in the vicinity of the programmer's console. All logging printers shall be functionally interchangeable.

c. Line Printers

Line printers, if provided, should be associated with each computer. These units will be located in the computer room. In addition to serving various programming and system diagnostic needs they will be utilized to produce a series of formatted reports on an hourly, daily, weekly, monthly, or demand basis.

d. Magnetic Tape Units

Magnetic tape units, if provided, should be capable of providing the following functional operations:

- Loading of programs into the ECS
- Receiving copies of the historical data file on a periodic basis
- Support of engineering studies
- Support of program development

e. Video Hard Copy Device

A single hard copy device capable of producing a facsimile of any CRT image, less color, should be provided. A video actuated device or character printer with a character set identical to the CRT display generator character set are acceptable approaches. An operator should have the capability of requesting a hardcopy of any image from any operating position.

f. Card Reader

A card reader, switchable to either CPU, may be provided for:

- Data base and CRT picture maintenance
- Loading of programs or data for engineering studies, etc.

g. Mapboard

A static mapboard panel should be considered. The graphics on the board would allow the Borrower to show the overall transmission and generation system in simplified form and permit the operators to view the total network. Detailed status of specific stations will be obtained from CRT displays.

h. Time, Frequency and Digital Display Panel

The ECS should have a panel which contains various displays and functions associated with time, frequency, backup AGC and display of selected system variables. This panel will house several digital displays visible from at least twenty feet away as follows:

° System time

° Time deviation

° Frequency deviation

° Operator selected variable

In addition, the panel should house backup analog AGC area control error (ACE) computation equipment and its associated controls and indications. The ACE chart recorder (Borrower provided) should be located on the chart recorder panel.

i. ECS Status and Configuration Control

A form of indication control should be provided which permits the operator, programmer, or maintenance engineer to determine the operational status and present configuration of the computer systems, peripherals, related communication channels and equipment. Control capability in the computer room should be provided, which permits switching of certain peripherals and commnunication devices from one computer to the other, and to allow manually initiated failover. The ECS status indication and control functions may take the form of a panel in the computer room and a CRT display in the control room.

16. Digital Communications Channels

Communications with the RTUs generally use half-duplex operation over 4-wire full-duplex channels operating at 1200 baud. Whenever possible, RTUs should be party-lined with a maximum of six RTUs per party-line. The Vendor should provide an analysis of worst case operational line loading considering the initial and maximum fully expanded number of points from each RTU.

The secure operation of the power system is of prime importance. Errors in data transmission, communication channel noise, and dropouts, shall not cause any improper power system control actions. The ECS computer shall constantly determine the integrity of the commnuications system, as a minimum, through the following forms of equipment malfunction and error detection:

- Error Detection Codes - Data transmission errors should be detected by use of error detection codes imbedded in the master station-to-RTU and RTU-to-master station messages. The error detection codes may be BCH of geometric codes. An RTU receiving a message containing a detected error shall not respond to that message. The master station receiving a message having an error detection code error shall successively reinterrogate the RTU up to five times. If satisfactory response is not obtained, the RTU and/or the communications channel shall be declared to have failed and an RTU/"channel out" alarm shall be set. After 15 minute duration, the master station should retry the failed channel and determine if the channel/RTU is usable again. Provisions for tagging the channel/RTU for no retry shall be provided.

- No Reply - If a reply is not received from an RTU, the ECS computer should reinterrogate. If after five successive retries there is still no reply, the RTU and/or the communications channel should be declared to have failed and an RTU/"channel out" alarm should be set. After 15 minute duration, the master station should retry the failed channel and determine if the channel/RTU is usable again. Provisions for tagging the channel/RTU for no retry should be provided.

- Wrong Reply - If the reply from an RTU is incorrect in address or function code, the message should be ignored and the RTU reinterrogated. If after five (or other selectable value) successive unsuccessful retries the RTU and/or the communications channel should be declared to have failed and an RTU/"channel out" alarm shall be set. After 15 minute duration, the master station should retry the failed channel and determine if the channel/RTU is usable again. Provisions for tagging the channel/RTU for no retry should be provided.

- Error Rate - If the number of any combination of errors detected on any communication channel or from any RTU exceeds a specified threshold of errors per unit time, the operator should receive an RTU/ "channel degraded" alarm.

17. System Data Scanning Rates

Power system data should be brought into the ECS from the RTUs via the digital communication network and from the local data acquisition systems. The RTUs are under the direct control of the system computer and in general, the scanning rates are:

- Two-second scan - For all status changes, generator, and tie line MW and MVAR and frequency measurements including local analog telemetry channels

- Ten second scan - For all other transmission line MW and MVAR, volts, transformer bank MW and MVA, etc.

- Ten-minute scans- For weather related quantities
  - For a system data base update of all status and alarm points

- Hourly scan - kWh broadcast freeze and quantities

- On demand - Any of the above data group selected by operator

- Generation Raise/Lower - Corresponding to AGC execution cycle (about once every two to eight seconds)

- Supervisory Control - Arming of interposing relay within one second of point selected on the CRT and completion of control action within one second

of execution command entry by the operator. Master station and the RTUs should have independent time-out counters to prevent the system from becoming locked-up (10 to 30 seconds)

- Demand Input - Capability to accept unscheduled arrival of information from the microwave alarm system and the master station

18. Local Data Input/Outout Requirements

Certain data will be either input or output to/from the ECS. These will include analog telemetry interfaces both in and out, chart recorder drives, status inputs, time and frequency transducer interfaces, digital displays, ECS teletype, and the WWV clock. A possible solution for interfacing some of these data is to utilize a "LOCAL" RTU.

19. System Sizing

A paramount objective in planning and designing the ECS is to assure that the purchaser will not be constrained by either hardware or software restrictions that prevent orderly growth over the next decade. Each part of the system shall be examined carefully to determine how expansion can be implemented in the future. Areas of particular importance include the:

- Data base design and main memory reserves and growth
- Data acquisition system
- Man/machine system
- Computer system throughput
- Mass memory reserves and growth

In order to accomplish expansion of change in an orderly manner, hardware and software shouldbe modularized. The total software shouldbe subdivided into many smaller packages, each with specific functions, clearly defined external boundaries, and relatively simple interfaces to other software packages.

Serious consideration should be given to the quality and ease of operation of the special conversational/interactive compilers used for generation of new CRT pictures and/or expansion of the data base as new points and terminals are added to the system. The vendors should explain in detail how this is to be accomplished.

The selection of a computer should be based on its capability to perform all the functional requirements as set forth in this specification while retaining adequate reserve capability for future growth and expansion. Certain minimal criteria have been established for the size and capability of the CPU, the main memory, and the mass memory. These requirements are:

- CPU Throughput - The initial system CPU should be size with at least 60% unassigned reserve capacity in processing capability, averaged over a 60 second time period during the worst case loading condition (includes all required application programs)

- Main Memory - The initial system main memory should average at least 25% of unassigned reserve core

- Mass Memory - The initial system mass memory should have at least 70% of its capability unassigned. The disk pack shall not have any permanent storage assignments

- Backup CPU - The backup CPU should be capable of handling a background FORTRAN program of at least 128k words

- Communications Channels - The initial communication I/O channel capacity should have at least 40% reserve capability

B. Hardware Considerations

This section prescribes the hardware requirements resulting from the functional requirements stated in previous sections. Hardware attributes that may be important include:

- ° High System Availability - By providing hardware redundancy for critical system functions, including manual/automatic switchover capability in the event of failures

- ° Real-Time Computers - To perform the system critical functions such as data communications, man/machine functions, data logging, and automatic generation control

- ° Man/Machine Equipment - To provide an efficient interface between the operators and the ECS

- ° Maintainability - To be designed into the system in terms of modularity, special test points, accessibility, and special test equipment

- ° Future Expansion - To be designed into the initial system such that it may be conveniently expanded as the information and control functional requirements increase and change over the years.

Where the borrower has a preference for specific hardware components, the manufacturer's type and model number or approved equal should be specified. If the vendor's proposed configuration does not make use of the listed hardware components, his proposal should contain additional detailed descriptions of how the functional performance requirements of the specification can be implemented.

1. Computer Subsystem

The system should consist of two identical computers with one fully capable of performing all system on-line functions. The other operating in the standby mode with its auxiliary memory periodically updated by the on-line machine.

The backup machine should monitor the frequency of the data transactions and automatically assume the role of the on-line machine should the data fail to arrive on schedule or have characteristics indicating a malfunctioning primary machine. Actual transfer should occur

when specified interrupts are raised between the two machines. Computers selected for this application must have identical characteristics, with emphasis on the following:

- High Availability
- Hardware and software designed for efficient real-time operation
- Flexibility for interfacing to a wide variety of external devices and systems
- Fully designed and implemented automatic failover hardware
- Capability and flexibility for expansion
- High performance CPU and input/output throughput

All computer and peripheral devices described herein should be from a standard line of equipment, manufactured and supported by the supplier. The following detailed specifications are for the purpose of identifying a minimal class computer system.

a. <u>Central Processing Unit</u>

The Central Processing Unit (CPU) should be selected so that the on-line machine shall have sufficient computing capability to support the total program components and the logic operation load required for the supplied hardware and software system.

The CPU should perform arithmetic and logical operations, control the on-line machine, execution of instructions, and control the exchange of information between the memory and other parts of the system. Listed below are characteristics considered acceptable for each CPU:

- Word Length - A minimum of 16 information bits
- Memory Addressing - The memory should be addressable by byte and word
- Indirect Addressing - Each CPU should have multilevel indirect addressing allowable

- Immediate Addressing - Immediate addressing of operations to be provided

- General Purpose Registers - A minimum of eight to ten addressable general purpose registers

- Index Registers - Two to four general purpose registers may be used as index registers

- Hardware Multiply/Divide - The central processor should contain arithmetic and control logic for performing high speed fixed point arithmetic using hardware implemented multiply and divide features

- Index Formats - Capability for indexing memory addresses by bit, byte, and word

- Instruction Set - 96-word instructions minimum

- Bit Manipulation - A set of bit manipulation instructions are necessary to enable individual bits in memory to be tested or modified

- Floating Point Arithmetic - Floating point hardware should enable the computer to perform either 32-bit or 64-bit floating point add, subtract, multiply and divide operations

- Machine Traps - Clearing of hardware and software operations provided by traps generated when abnormal conditions occur

- Multiprogramming - Hardware and software features are necessary to enable multiple programs to time-share computer operation

- Real-Time Clock - A real-time clock and interval timer are necessary for use in real-time system control and time allocation

- Hardware Bootstrap - A hardware bootstrap capability to allow system reload from disk and magnetic tape

- Control Panel - A control panel is required to provide manual computer control. Associated with it should be an automatic program load feature and an addressable program halt

feature in addition to all necessary controls and displays for loading and displaying register or memory content and for performing all required control functions

- System Protect - A system protect feature is required to prevent unauthorized intervention with computer operation

- Memory Page Protect - A memory page protect feature is required that will enable the privilege violation trap to be generated if the machine is operating in an unprivileged state and attempts execution of an instruction which modifies the contents of any protected memory location

- Privileged Operation - A privileged operation feature is desired as a safe-guard against attempts by two or more programs to use the same computer resources.

b. <u>Direct Memory Input/Output System</u>

A direct memory input/output system is required which enables input data transfers to be performed independent of the internal operation of the machine. The input/output system should be structured to eliminate central processor lockout caused by peripheral device response time. The CPU should initiate block transfers of data and then proceed with internal operation while the transfers occur in an instantaneous manner. Data block transfers should be made up of bytes, or words, and peripheral devices with minimum data rates of one million bits per second. Output channels should be completely buffered to permit the input/output system to handle high speed single peripheral devices or a number of low speed devices.

c. <u>Main Memory</u>

Each real-time computer provided should have a private high speed main memory made up of either core or semiconductor elements. Required characteristics of the main memory are as follows:

- Capacity - The initial main memory for each machine should be stuctured for the requisite

number of words and expandable in a modular fashion

- ° Cycle Time - One microsecond maximum (word access)

- ° Word Length/Parity - It is desirable that for each information set bit stream an additional parity bit be provided. Parity should be automatically generated and checked on each read or write operation

- ° Memory Access - Memory should be supplied which permits direct random access for the CPU and the I/O system

- ° Memory Power Supply - If a semiconductor memory is utilized, a memory battery power supply must be provided to save the memory contents in the event of a power interruption.

d. <u>Mass Memory</u>

Each real-time computer should be provided with rotating disk random-access mass storage devices with moving recording/playback heads. Under normal operating conditions the on-line computer updates the disk memories on both computers simultaneously with system data base parameter changes. The path may be either CPU-to-CPU communications channel, or dual ported disks. The backup computers shall have the capability of updating its own disk memory and obtaining information from the primary or on-line computer disk memory from priority control by the primary computer.

e. <u>Priority Interrupt System</u>

A priority interrupt system should be provided with individual priority levels, each with a unique location assigned in memory, each with a unique priority, and each capable of being selectively enabled and disabled under program control. An interrupt priority structure which permits an interrupt servicing routine to defer a portion of processing associated with an interrupt level by first processing the high priority portions of the routine and then triggering a lower priority level is desirable.

Priority interrupts are basically divided into two groups: internal interrupts and external interrupts. The internal interrupts are normally associated with the CPU and I/O system operations such as:

- Power failsafe processor fault
- Memory fault
- Input/output data transfer
- Control panel interrupt
- System protect interrupt
- Program traps

External interrupts which are normally assigned to various components of the control system, such as light pen selection by the operator or communications line buffer signals, should have the capability to place each external interrupt in one of the following states:

- Disarmed - No signal to that interrupt level is admitted
- Armed - The interrupt level can accept and remember an interrupt signal
- Waiting - A state where an interrupt signal has been received and is waiting to be advanced to the active state
- Active - The state where the CPU will immediately execute the control of the assigned interrupt location of the next instruction

External interrupts should be identical for both computers. One external interrupt for each machine is used to accomplish primary/backup computer signaling.

f. Computer Console

A computer console panel which permits manual control of the CPU by manipulation of toggle switches on the face of the panel is desirable. Switches should be provided which permit altering the content of the computer memory and registers. Visible registers

which permit reading the content of selected registers are desirable. This panel should permit programs to be started, halted, or single-cycled. The computer should permit the contents of memory to be displayed, cleared, and loaded. Indicators that permit the computer operator to monitor the status of the various elements of the computer are also necessary.

g. CPU-to-CPU Channel Interface

An I/O channel between the two CPUs is required for high-speed exchange of disk update between the on-line and backup machines and general system administrative messages. The high speed requirement may be waived if dual-ported disk controllers are to be used. These channel devices should be connected through compatible interfacing equipment to assure the maximum data transfer rate is achievable.

h. Watchdog Timers

Watchdog timers effect a failover for any device or software routine impairing the successful operation of any critical function.

Watchdog timers should be purchased as part of the system. These may be part of the CPUs or supplied externally. Failure of the on-line machine to reset its performance monitoring timer within a specified time will cause the system to failover to the backup system.

i. Computer Keyboard/Printer

Properly interfaced console Keyboard-Send-Receive (KSR) type keyboard/printers should be considered. These devices are used primarily by software programmers and maintenance personnel in program development, maintenance activities, troubleshooting, system cold start up, etc. The devices should be interchangeable with,and the same manufacturer type as the operator/alarm loggers.

j. Card Reader

A card reader with associated controller should be acquired to support program maintenance and background processing. This unit shall be manually switchable to either computer.

k. Magnetic Tape System

Magnetic tape drive units with associated controllers should be considered. The tape drives are used in support of programming operations and for the storage of historical information. The magnetic tape systems may have the following general characteristics:

° Tape Size - One-half inch by 732 meter reels

° Recording Density - 630 bits per cm (phase encoded)

° Recording Format - 9-track

° Read/Write Speed - Tape speed of 1.143 meters second

° Error Detection - To insure data recording accuracy, the magnetic tape system should perform read-after-write check. On completion of recording the tape station shall receive and record both the cyclic and the longitudinal redundancy check characters

l. Line Printer

Fully buffered line printers should be employed in the ECS. One printer may be used with the on-line machine for printout of scheduled and generated reports. The other printer would be normally associated with the backup machine for support of program development, updating and modifications.

m. Power Fail-Safe

Each real-time computer should have the capability to detect the imminent failure of the primary AC power, and with the aid of a software routine, bring an orderly halt to computer processing.

Each computer should continuously monitor the primary AC power line voltage and if a specified drop in line voltage is detected, the computer should be interrupted such that the computer initiates a shutdown routine to store the contents of all volatile registers in the main memory, and come to a halt condition. The subroutines should have, as a minimum, four milliseconds to perform all necessary functions.

During this period, the DC power required to operate the CPU and main memory shall be maintained by the energy stored in the power supply filter capacitors.

As the primary AC power is brought back to normal, the power fail-safe feature detects the condition and again notifies the computer via an internal interrupt. This action initiates a startup routine to load registers with data stored during shutdown routine and resume processing.

n. Floating Point Processor

Each computer should be supplied with a floating point processor (FPP). The FPP is capable of high speed floating point arithmetic. It should provide for a single-precision (32-bit) and double precision (64-bit) operation. The system should be able to support simultaneous parallel operation with the central processor.

o. Data Channel Multiplexers

Redundant data channel multiplexers should be provided. This equipment must be capable of simultaneous data transfer between the interfacing control computer and the communication data channels.

The multiplexer should interface with the standard computer I/O data channel and be capable of transferring data bi-directionally. The multiplexer should provide and effective data link between the computer memory and slow devices, such as loggers, local data conversion equipment, and communication data channels operating at various transmission speeds.

All multiplexer I/O operations should be program controlled; once data transfer program is initiated, the multiplexer should totally relieve the central processing unit from the details relating to the I/O transfer. Data transferred between any of the multiplexer ports and external devices should be completely asynchronous utilizing a "hand-shake" type protocol associated with the various peripheral devices. Peripheral devices or communication data channels should notify the multiplexer when they are ready by the use of priority structured interrupt channels.

p. Data Channel Controller

The communication channel controllers act to provide the actual communication between the I/O multiplexer and external devices (RTUs or peripherals). The controllers provide the serial to parallel data format conversion to the multiplexer from external devices, and the parallel to serial conversion in the opposite direction. Each controller should include sufficient buffering to accomodate the substantial change in data transfer rates through it.

Communication data channel controllers must be capable of interfacing to communication modems operating at rates up to 4800 baud, or interfacing to current line drivers for operation with other peripheral devices.

q. Communications Switching

The control system should provide for a communication switching panel arrangement for:

- Manual - Rerouting of signals at both the analog and digital side of the modems, for insertion of test equipment leads, or for miscellaneous communication line/modem switching

- Patching - Around failed modems for substitution of standby modem

- Monitoring or Testing - Telephone circuits or data channel multiplexer/controller interfaces without interruption of on-line traffic

- Loop-back Patching - At either the analog or digital side of the modem, either toward the data channel multiplexer/controller interface or toward the communication circuits.

The communication switching panel should contain provisions for handling all analog and digital circuits.

2. Remote Terminal Units (RTUs)

The remote equipment supplied for a substation or power station should be of the same basic design and functional capability but of variable configuration, depending on actual point counts at various locations.

The RTUs may be furnished in several sizes. Each size utilizes the same basic input/output elements but may vary in quantities of internal components: card files, power supplies, PC cards, wiring, etc. The borrower should determine the RTU sizing for initial, spare and future points.

All remotes should have the following functional capabilities:

- ° Data acquisition
- ° Supervisory control
- ° Data communication and, as may be required,
- ° Automatic generation control.

a. <u>RTU Expansion Provisions</u>

Each remote terminal unit provided should be configured to accommodate all "initial" and "spare" points. All defined "future" points should be implemented by the addition of plug-in point cards and relays only, not by the addition of common logic, card files, power supplies, cabinets, terminal strips, and the like. Power supplies and cabinets should be sized to accommodate initial, spare and future and an additional 25-percent capacity.

b. <u>Data Acquisition</u>

The remote terminal equipment serves as the main interface between the power system and the ECS master station. The power system input signals fall into the following basic categories:

(1) <u>Analog Inputs</u>

Analog input signals are defined as: "those variable quantities or representation of information which bear an exact relationship to the original variable."

Standard power system transducers generally will have dc current output ranging from 0 - 1 ma into a load impedance of equal to or less than 10k ohms. The analog inputs should be ungrounded differential type inputs such that two RTUs can

monitor one transducer output. The vendor should be capable of supplying adequate signal conditioning to provide suitable interfaces to these and other analog inputs. Analog conversion and resolution should be provided. Common mode rejection should at least be 100 dB at 60 Hz and differential mode rejection at least 60 dB at 60 Hz.

Each analog input may require a surge protector and filtering network to provide protection against high voltage transients and common mode noise signals. Additional filtering networks should be used, if required, to minimize sampling errors based upon the scan time requirements. Two precision voltages should be provided for each analog-to-digital conversion (ADC) as calibration and check points for the analog-to-digital conversion.

(2) Status/Alarm Inputs

The remote terminal unit status/alarm input function provides the capability to scan status/alarm inputs and store information concerning the current status/alarm state and changes in the state that occur during successive scans. Status and alarm inputs are to be provided from external dry contacts either Form "A" or "B". Two types of point logic are required; one for indication only and one for indication plus transient status detection. For momentary contact detection (of at least 10 msec duration) status change memory capability should be provided. External contact operation may be: open to close, close to open, momentary close or momentary open. The RTU should not reset its status memory bit until it receives an acknowledgement from the master station that the status memory data has been received.

The RTU should be provided with separate modules capable of accepting and accumulating contact closures from kWh meters. The accumulator and buffer registers should also have the capability to accumulate and store at least 12 binary values. Separate accumulators may be used for monitoring kWh "IN" and "OUT" values. The accumulator should be capable of operation from 2-wire Form A or B

type contact and from 3-wire Form C type anti-bounce contacts.

The contents of the kWh accumulator are transferred to a buffer register upon receipt of a freeze command. In most RTU locations the freeze command will come from the master. In some instances the freeze command may be initiated by a contact closure in kWh accumulation equipment. Whereas in other instances the remote will produce a contact closure concurrent with its receipt of a freeze command from the master, to remotely freeze the accumulator in the kWh equipment.

To facilitate interchangeability, each remote having kWh accumulators and located at an inter-tie point should be equipped such that it can either accept a local freeze command in the form of a contact closure from a foreign remote. Subsequent to receipt of the freeze command by either source, the data in the accumulator should be buffered out and the RTU accumulator should continue to count. The buffer register should remain unchanged until filled with new data upon receipt of the next freeze command. The buffer shall be readable by the master station at any time and as many times as required by the data acquisition programs.

Contact closure inputs should be isolated and filtered for surge and transient protection to avoid multiple counts due to contact bounce.

c. Control Outputs

The remote terminal units provide the capability to control interposing relays upon command from the control center for supervisory control. Interposing relays (IPR) should be provided for breaker and other momentary contact closure type operations. Latching type IPRs shall be available if required. The signal from the master station closes the relay and a subsequent signal releases the relay.

A remote terminal unit used for automatic generation control should provide the capability to operate interposing relays for governor motor actuator raise or lower. A generation control output command operates in the immediate execution mode with an acknowledgement message sent to the computer based

control equipment.

d. Local/Remote Indicator

Each Remote Terminal Unit should be equipped with a Local/Remote switch. With the manual switch in LOCAL position, all data acquisition functions are available at the control center; the supervisory control functions are then available for test purposes only, and no operation of the power system devices may take the place from the control center. A status indication that the RTU has been transferred to LOCAL mode when the manual transfer switch is set to LOCAL position is available at the control center.

In the REMOTE position the RTU provides for data acquisition, supervisory control and system routine test functions.

e. RTU Power Supply

The vendor should provide adequate protection for the RTU equipment from voltage transients as a result of switching, or other devices which may derive power from the same battery. Similarly, normal operation of the RTU should not introduce into battery power supply any transient greater than 0.75 volt peak-to-peak.

3. WWV Time Synchronizer/Receiver

If a WWV/WWVB time and data synchronizer for receiving NBS radio station time and date codes is to be provided, the unit should have the following minimal features:

- Automatic on-time synchronization with NBS radio station WWV/WWVB
- Self contained WWV/WWVB receiver
- Propogation compensation of a transmission delay
- Internal oscillator for continuous operation (stability of $\pm 1 \times 10^{-7}$ per week)
- Appropriate interface for operation with the master station computers.

C. Software Design

The software development cycle consists of three parts: analysis and design; coding and debugging; checkout and test.

Analysis and design is the most important phase of software development and should be carried out as thoroughly as possible. Problems in coding, debugging, checkout and testing, and in maintenance, are largely attributable to a poor analysis and design. This initial phase of software development specifies the individual program modules, the inputs, outputs, tables used, tables updated, and the algorithms. Design decisions are made on the data base structure and access method, table and file structures, data update requirements, and backup requirements. All hardware-to-software and software-to-software interfaces are spelled out. Initialization procedures, CRT and logger messages, maintenance requirements, test procedures, and acceptance criteria are all specified. All this must be done, reviewed, and agreed upon before one line of code is put on paper. All too often the natural tendency to get going and start coding gets the better of the software designers and the analysis and design effort gets hurried through. This is an invitation to disaster.

The coding and debugging phase typically should take less than 25 percent of the entire software development work. Most of the real-time application software for control centers have been written in assembly language. However, the capabilities of FORTRAN for real-time use have improved and there is a growing trend toward more use of this language. Whatever language is used careful attention must be given to those program features which affect real-time linkages, response times, and program reliability.

The real-time linkages of a program consist of: accesses to the database; I/O requests to use and/or update files; I/O requests for CRT display and logger messages; program execution requests. Good response means an efficient code, a minimum I/O, effective use of subroutines, and proper use of interrupt control program reliability means use of fail-safe logic, proper initialization on system startup, evidence of timing problems, invulnerability to bad parameters, control of possible arithmetic overflow, and proper handling of error returns on I/O and program execution requests.

The checkout and test phase takes up the rest of the software

development work. The individual program is tested in the foreground in as complete a real-time environment as possible. The real-time environment is built up gradually as each program is integrated into the system. When the entire system is put together, hardware and software, the individual program tests are repeated as part of the system checkout. The acceptance tests complete the test cycle. The test drivers written for the individual program tests are kept for later use in system maintenance.

1. General

The vendor is responsible for providing software in an operational ready state. System performance should be fully demonstrated as a condition for final acceptance in accordance with software design requirements mutually agreed to between the Borrower and Vendor. If possible, and whenever practical, the Borrower should use the Vendor's standard program packages.

Successful implemenation of the software requirements includes:

- Identification of specific programs and files and their organization necessary to satisfy the requirements of the specification

- Design, coding, debugging, and documentation of individual programs

- Integration of all programs into an effective and efficient software system

- Demonstrate by test of overall system performance against the requirements of the specification

Main and memory maps and program run times which show the allotments for all individual programs and data files required to meet this specification should be obtained from the vendor.

The software requirements discussed herein are for the following major categories:

- The operating system

- System software

- Application software

- Programmer's aids

The operating system, provided by the computer supplier performs a variety of tasks, including:

- Scheduling and performing I/O functions
- Interpreting operator or other input commands for specific tasks
- Scheduling and allocating tasks
- On-line and off-line debugging and diagnostic services

The control and or energy management system software provided by the control or energy management system Vendor consists of the following program categories:

- Data communication control
- Man-machine programs for CRT displays, console controls, logger printers
- Special handlers required for external interfaces not standard with computer supplier
- Special scheduling services for power application programs

The software systems provided should be designed and implemented in accordance with the following general guidelines:

- The overall software shall be responsive to the system operational and functional requirements
- The software design should not require basic modifications to the computer manufacturer's operating system
- Straightforward interfaces should be established between the applications programs, the operating system, its enhancements, and the data base
- A well-structured data base shall be provided with associated manufacturer's features which are independent of display and application programs

- All software shall be designed with a high degree of modularity and minimize impact of future changes and will simplify test and evaluation routines.

- Use of the Vendor's software which has previously been utilized on other projects is encouraged to minimize cost and risk.

- The software shall be designed so that it is not necessary to reassemble or recompile the system in order to accommodate clearly anticipated system growth.

- Adaptability for expansion to accommodate normal changes should be based on the concept that the number of parameters, the location of parameters, the processing given each parameter, and the display list be under data base management control.

- System software may be written in assembly language; however, the purchaser prefers all applications to be written in FORTRAN. Bidder shall state what language programs are written in.

If the system procured consists of dual computers and their associated peripheral devices, communications and man-machine interfaces, the two processors shall be identical to each other with their roles reversible at any time. In normal operation one of the processors shall perform all system functions and the other processor shall be a backup. Certain functions, such as program development and program compilation, may occur on-line using the backup machine. A summary of functions for the two processors is provided below:

Primary machine

- Provides all external communications control for electric system remote terminals and local data conversion

- Provides communication to all man-machine devices

- Performs application programs on schedule or on demand

- Provides a copy of control system data on a periodic basis to the backup machine in the event the primary machine should fail

Backup machine

- Provides immediate backup to the primary machine in the event the primary machine fails

- Periodically tests the primary machine for normal operation

- Provides processing resources for program development and program compilation

2. The Operating System

The basic operating system is one which is provided by the computer manufacturer and is a fully supported programming system. It is recognized that required enhancements are generally provided by the control system vendor; however, these enhancements should not invalidate future support of the operating system from the computer supplier.

a. General Requirements

An operating system is provided with each processor which monitors and manages the allocation and use of the individual processor resources and the combined requirements of a dual system.

The operating system is generally interrupt/event driven and capable of multi-programming. Several main memory resident programs and several non-resident programs should be able to run concurrently with a background program with emphasis on protected foreground operations. The operating system should take maximum advantage of secondary disk storage to ensure efficient monitor and user operations. The disk shall be used for storage of overlay portions of monitor and system processors, thus minimizing utilization of main memory. Storage areas for service programs, processors, libraries, and user programs shall be available on the disk. Among the main functions of the operating system are:

- Control overall system resources and prevent two or more programs from simultaneously accessing the same resource

- Permit new programs to be added and tied into automatic scheduling with a minimum of effort

- Provide I/O handlers for all standard and non-standard interfaces

- Process all requests for program execution based on external or interrupt events
- Schedule programs on a priority basis and assure that no program execution will be unreasonably delayed
- Provide FORTRAN interfaces with all external devices
- Pass parameters to a requested program via main memory or disk storage
- Request other programs periodically or on demand
- Transfer critical portions of the data base to the backup system on a periodic basis
- Perform diagnostic checks, automatic failover, and automatic restart
- Convert data from one format to another
- Handle unsolicited I/O interrupts from the operator or other programs
- Provide re-entrant service functions to perform I/O and other functions
- Provide protection of programs and data files against inadvertent or unauthorized modification
- Provide services for system generation

b. Real-time Scheduler

A Real-Time-Scheduler should be provided which regulates the processing of system and application programs. The scheduler performs the following basic functions:

- Initiate task execution for cyclic programs
- Initiate tasks resulting from the occurrence of events for specified conditions of the power system
- Initiate tasks resulting from operator requests or actions

Capability shall be provided to schedule cyclic programs at any time within a 24-hour period with a resolution of one second. The system should provide a calendar time

program that provides the date, hour, minute, and seconds for display and program scheduling. Time adjustments for local standard and daylight savings time should be easily accomplished by the operator and automatically referenced to an external WWV signal. Following a system restart, the system clock should automatically reset to the correct local load time as synchronized with WWV.

c. Program Security

The operating system ensures the protection of all data files against inadvertent or unauthorized modification. In addition, a procedure shall be provided to restore system files and ensure fast recovery in the event of hardware failures. The backup disk must contain a subset of information contained on the on-line disk. Mass storage files should be updated as soon as system parameter changes are received or historical data are retrieved or calculated. Data base transfers to the backup disk occur from either CPU and are capable of being transmitted to the other CPU for file update.

d. System Surveillance and Failover

The operating system monitors an array which contains information concerning the computer configuration. This information is used when initiating processes and to determine when degraded conditions exist. The operating system should contain an equipment status update program for the purpose of declaring whether a device is either up or down.

A number of different failure modes are possible in systems of this type. Not all failures will justify a complete switchover to the backup system as some will only cause alarms to the operator. Several failure modes are described with the preferred action resulting from each:

- Critical Device Failure - When a critical device such as the mass storage unit on the primary system fails, a full failover to the backup machine is required. Such failures should cause an alarm and be logged out on an alarm logger.

- Non-critical Device Failure - When a non-critical device, such as a magnetic tape transport, card reader, or printer should fail, no master failover sequence

is desired. Such failures should cause an alarm and be logged on an alarm logger.

- Software Switchable Device Failure - With some system configurations certain hardware failures can be circumvented without overall system switchover by switching to an alternate device via program control. In the event of a failure of a particular device, an alternate device may be brought into service under program control without a complete system failover. In the event this occurs, an alarm is raised.

- Other Failure Conditions - Whenever processor fault occurs in the primary machine a master failover occurs. The failure causes an alarm and is logged on an alarm logger.

e. I/O Control and Processing

Both standard and special I/O drivers and handlers shall be provided for communication with all external devices. The processing requirement to service these handlers and drivers should be minimized. All I/O processing shall provide for error checking, buffering, and format control.

f. System Initialization and Restart

An initialization module should provide for all necessary information for system initialization. Included in this process is table initialization for the total system followed by a call-in of permanent processes. A restart module automatically initiates the required action and restarts the system.

Subsequent to any system outage and system restart where the system (time) clock may have been altered, the internal time clock automatically resets to the time receiver.

3. Communications Software

Software is required to support message exchange for all scan modes, generate the necessary commands to retrieve power system data and status information, and perform the requried error and reasonability limit checking to insure the validity of the received information.

a. Data Scanning and Security Checking

Received data is to be checked against reasonableness and

operational limits and all bad data flagged and alarmed. Scalar quantities are converted to engineering units, the real-time data base updated at appropriate intervals, and status information examined for alarms. The operator should be able to inhibit the update of any selected quantity in the real-time data base and to substitute a manually-entered value if desired.

A periodic diagnostic check or malfunction detection scheme should be provided for all channel adapter/ modem combinations. In the event of malfunctioning units, a method should be provided to allow simple or automatic by-pass reassignment to the standby units. The automatic detection of a defective unit raises an alarm.

Communication system alarms accumulate in the alarm file for subsequent logging and display. These alarms include but are not necessarily limited to:

- Excessive rate or total count of detected transmission errors
- Failure of an RTU to respond
- Failure of channel adapter or modem

The message structure from master to remote and remote to master must have the same level of security. Security coding and decoding shall not be performed in the main processor unit.

b. Data Conversion and Limit Checking

Each type of information obtained by the master station shall be grouped according to source or function such as station, kWh intertie quantities, etc. For each group, unique table-driven logic is provided which permits conversion and limit checking of the measured quantities or status. Typical information or processes associated with these data include operational limits, reasonability limits, measurement type, data identification, conversion factors, position in group, etc. The programming provides at least the following functions:

Operational Limit Checks - Performed on all incoming telemetered measurements. The operational limits consist of a high and low value entered by the operator.

Reasonableness Checks - Performed on all telemetered measurements which fail the operational limit check. In addition, reasonableness checks are performed on all manually-entered data at time of entry. Reasonableness limits will normally bound the maximum possible range of each measurement. Should the reasonableness check fail or if a syntax error is detected, an additional bit is set in the real-time data base. The setting of the failed reasonableness check from a manual entry causes an error message or invalid entry announcement to be presented to the operator. The bit is reset by the operator clearing the entry. If the bit is set because a telemetered value failed a check, the bit causes an alarm to be presented to the operator. Return to normal range resets the bit. The magnitudes and sign of the reasonability checks are independent of the operational limit check magnitudes and signs with the exception that reasonability limits should always be greater than the operational limits.

Data Scaling Factors - Provide for conversion of raw data to engineering units.

c. Data Processing

Capability can be provided for the operator to interactively create computed digital data points from other data residing in the data base. These points are then available the same as any other points in the data base. The following operations should be available as a minimum for operation on analog data:

- Sum
- Difference
- Product
- Quotient
- Square
- Square Root
- Maximum value and time (hourly and daily)
- Minimum value and time (hourly and daily)

The following logic operations should be available as a minimum for operation on discrete data:

- Or
- And
- Exclusive or

The processing interval for data computed points should be initially selectable from either of two values. One should be every scan time, and the other should be approximately once every 30 seconds. The calculated data shall have the quality characteristics of the least credible data used in the calculation.

d. Local Data Interface

In addition to acquiring data via RTUs, certain data may be acquired locally from analog tone channel receivers, master, local status, microwave alarm, etc. Local outputs are provided for chart recorder driving and for drive of several panel-mounted digital readout devices.

(1) Analog Data Acquisition

Certain data acquired via tone channels and used for chart recorder driving may be acquired locally, converted and entered into the ECS data base. The necessary communication handlers shall be provided for acquiring local analog quantities at two second intervals.

(2) Digital Display Drive

Software is provided for driving digital display devices mounted on the chart recorder panel. The operator should have the capability of assigning any of these devices to any real-time or computed value available in the data base, scaled or unscaled, through an interactive CRT display.

(3) Chart Recorder Interface

Software is provided for driving the chart recorder channels. Several channels should be assignable by the operator via an interactive CRT display to any quantity in the data base. Scaling shall normally be set to utilize recorder full scale. In addition,

scaling in the form of ax+b shall be assignable to each channel by the operator. Each channel shall be updated once per ten seconds.

The balance of the chart recorder driver channels should have the same basic attributes as the operator assignable channels except that the assignments may be made by a programmer.

(4) <u>Microwave System Alarms</u>

A software system may be provided for accepting and processing alarms originating from as external microwave alarm monitoring system. Microwave alarms will be received in the form of a serial string of ASCII characters when alarms occur. Processing and display of microwave alarms shall be consistent with the overall system alarm requirements.

4. <u>System Data Base</u>

A structured data base should be provided which is the common interface between the data acquisition functions and all user programs including displays, logs, reports, and application programs. Functionally, the data base consists of at least nine separate parts as follows:

° Real-time data base (including pseudo and silent points)

° System parameter data base

° Results file

° History file

° Alarm file

° Off-normal status file

° Substation action file

° Disturbance file

° Real-time data base dump

The system data base generally contains all information required by the user programs. The overall data base is initially sized to accommodate all real-time data.

a. Data Usage and Coding

A number of coding indications should be provided in the data base for each real-time data point. The coding should indicate to using programs special conditions which apply to a given data point. The following conditions for coding indications are considered minimum:

- Analog value or status point condition
- Analog value high operational limit
- Analog value low operational limit
- Analog value high operational limit exceeded
- Analog value low operational limit exceeded
- Analog value low out of reasonability limit
- Analog value high out of reasonability limit
- Analog value low out of reasonability limit exceeded
- Analog value high out of reasonability limit exceeded
- Analog scaling factor and offset
- Status point normal state
- Status point in off-normal state
- Alarm classification (critical, non-critical)
- Unacknowledged alarm
- Point taken out of scan (by operator)
- Alarm is inhibited
- Data is manually substituted value

- Data not being updated (due to telemetry failure)

- Preferred data source

- Backup source of data being used

- Point is in tagged condition

In some instances data for a given parameter may be obtained via two different system inputs such as, analog tone telemetry data and digital telemetry data being received via the RTU. In such cases two values for a given parameter reside in the data base. Generally,all using programs have a preferred data source and automatically switch to the backup data source in the event that the data quality is degraded. The operator should have the capability of designating the preferred data source on an individual point basis.

Integrated MW values may be used as a backup data for the hourly accumulated MWh values. When backup data is being used it should be so quality tagged. Also, integrated MW values may be automatically compared to accumulated MWh values and alarmed if the difference between the two values exceeds an operator-specified limit.

The system should provide the capability for silent points. Silent points are those devices which are not being monitored by an RTU or points at a station that does not contain an RTU. The state of these devices are changed manually.

All data shown on CRT displays should indicate the appropriate level of data quality. This includes real-time calculated data values.

In the event of detectable communications failures and out of reasonability range, the last valid data value generally remains in the data base. Certain using programs trip or stop operation until valid data is once again deposited in the data base.

b. Real-Time Data Base

Data stored in the real-time data base is that provided by the data acquisition system. Operator-entered data may override missing or erroneous

telemetered data. All manual data entries are to be checked for reasonableness, to include a check against the reasonableness limits, and for invalid character entries. The capabilities provided include calculated values which have been derived from telemetered real-time data base.

The real-time data base maintains all quantities, status, and special coding information resulting from each scan cycle or from operator entries. All data should be table-driven and stored in a form directly usable by user programs in either assembly language or FORTRAN. All frequently-scanned data should be resident in the main memory.

Data and status processing should be performed for implemented points only such that spare future data or status points are neither processed or alarmed.

c. System Parameter Data Base

Data stored in the system parameter data base include constants, curves, and other data which is normally entered manually by the programmer or operator. Frequently accessed data is main memory resident and all parameter data is table-driven.

Facilities should be provided for entry of parameter data either by a system programmer or the system operator. The choice and mechanism will depend on the particular parameter and the frequency of entry or change. Infrequently entered data may be entered by the programmer with the aid of the data base compiler described elsewhere in this specification. Operator entries are made by keyboard in conjunction with interactive CRT displays associated with specific power system applications. All operator changes should be logged on the operator action logger.

d. Results Files

Computed results from programs should be stored in a file which can be accessed by other programs, displays, logs, or reports which require these results as inputs.

e. Report History Files

The history file is a disk-based file which stores a given set of hourly information for subsequent generation of hourly, daily, weekly, and monthly reports. The file is initially sized to store, on an hourly/daily basis, 200 quantities for a period of 40 days. Provisions should be made for CRT display of any portion of this file and subsequent operator correction or substitution of data items. This file contains selected hourly history data for more full days and daily summary data for the remaining 30 days. All data should be identifiable and selectable for display or report generation on the basis of month, day of month, hour of day if in the first seven days, and individual parameter. Day number one shall be considered the previous 24-hour period where all hourly entries have been completed.

A storage routine should be provided which permits daily transfer of hourly data from the history file to tape, or daily transfer to a separate disk pack and monthly to a magnetic tape.

Capability should be provided to remount history file disks or tapes for subsequent record modifications and reissuing of reports, or for planning and engineering studies without disrupting on-line activities.

The following information is stored directly or computed and stored in the history file each hour:

- MWh values from each generating unit
- MWh values from each tie
- System MW load
- EKP MW load
- Net generation
- System time error
- Inadvertent interchange (on-peak and off-peak)
- Payback correction control error-integrated
- System Lambda

- Daily one-hour minimum system MWh load
- Daily one-hour maximum system MWh load
- Net scheduled interchange integrated on hourly basis to account for effects of ramping
- On-line reserve
- Net interchange for boundary ties (in and out)
- Net interchange for KU loads in EK area
- Net interchange for EK loads in KU area
- Boundary schedule by company and type
- Other data as necessary for monthly report generation

f. Alarm File

All active alarm messages for the power system, the microwave system, or control system are stored in an alarm file. Data is obtained by limit checking and alarm generation programs. Each alarm message is presented as English language information on either a CRT display or the alarm logger. Each alarm message should carry a critical/non-critical attribute. Alarm messages may be deleted from this file by the operator or in some cases automatically when the alarm condition has returned to normal.

g. Off-Normal Status File

An off-normal status file may also be provided with storage characteristics similar to the alarm file.

h. Substation Activity

A substation action file should also be considered. This message file would contain a time-tagged record of remote station status change activity. All circuit breaker status changes, whether caused by automatic action or supervised, would be stored. In addition, other selected status changes may also be stored. The file may be created by sorting on device descriptors from all incoming alarms and from supervisory control actions.

i. Disturbance File

A system disturbance file should be provided which stores pre-selected real-time values in a rotating file. Under normal conditions the file should store the previous few minutes of data. When a system disturbance occurs the next several minutes of data will be stored. The occurance of a system disturbance may be determined by either of two methods: (1) an assigned value to the file exceeds a stored limit (in the alarm program); or (2) the operator initiates by depressing a special function key.

j. Real-Time Data Base Dump

Capability should be provided for the operator to store up to three separate snapshots of the real-time data base on a disk. Providing a tape deck is available, the stored snapshot could be transferred to tape when computer resources are available. Each real-time data base snapshot should also be time-tagged. This function can be initiated by a special function key or by actuation of a CRT poke point.

5. Man-Machine Software

The software must satisfy the system functional and operational requirements. The requirements are concerned with the use of the operator's consoles, their associated CRT displays and entry and control devices, system logging devices, chart recorders and panel-mounted digital displays.

a. CRT Displays

Characteristics of each CRT display should be described in a format description table. These tables provide the data to be processed and the format to be used; that is, display field position, color blink, and status. A real-time formatting routine takes this information and converts it into suitable formats for driving CRT display generator equipment.

The man-machine programming provides for the servicing of all operator inputs from each console. Data entry occurs by the operator entering data on preformatted or in established fields on CRT displays. Routines are provided for checking validity of input data and have a one-for-one response with the operator.

Manually entered data replaces automatically entered data and remains until the operator removes this constraint. Manually entered data for AGC shall cause an automatic request for operator review once each hour. This may be in the form of an alarm.

Programming is provided to service individual CRT functions. The following functions are typical and are based on the utilization of a CRT picture generation program which is described in a subsequent section:

° Display Control Functions

Service requests for CRT displays

Call and schedule routines required to complete the servicing of requests.

Set up linkages to routines and files for display frame retrieval, dynamic update,etc.

Check availability of all facilities defined in routines prior to attempting the servicing requests

When errors occur, identify and return diagnostic error information to the user

° Display Selection

Provide a selection mechanism using the keyboard and/or light pen

Provide a page forward/backward capability including wrap around

Provide a display destination selection capability

Provide subsequent level display detail call-up

° Display Retrieval

Obtain dynamic and static information from memory and combine into single picture file

° Update Functions

Access all dynamic elements from the data base for picture frames currently being displayed

Periodically update all dynamic elements currently being displayed per the latest status and measurement values

Update only those dynamic elements that have changed since the last periodic update

° Applications

Provide routines as required to satisfy operational requirements

° Data Entry

Provide a data entry facility

° Input Editing

Provide an input editing function and error message generation in accordance with the operational requirements

b. Console Keyboards

Two forms of keyboard control are generally used for the console. A general purpose keyboard containing standard alphanumeric quantities, CRT graphic symbols, and CRT edit functions interfaced to the CRT display generator, and a separate set of special function keys should be considered. These special function keys may be used for station menu selection, application program menu selection, display menu selection, and various control functions such as TRIP, CLOSE, RAISE, LOWER, ENTER, CANCEL, VALIDATE, CLEAR, TAG, TAG REMOVE, EXECUTE, INHIBIT, etc. Some of these functions may also be duplicated as poke points on the CRT display. Depression of these keys shall result in an interrupt to the on-line computer requiring near-immediate service of the request. All requests to the computer shall be acknowledged in some form indicating to the operator that the system has received and is processing his request.

c. Logging and Report Generation Programs

The functional capability of the logging printers should be operator assignable by individual function or combined function if its units are available. Provisions should be made such that no data is lost if a printer is required simultaneously by more than one using program. After printout of a message, the line feed shall advance to permit good visibility of the last line without the necessity of manual feed advance. The printer motors will start and stop under automatic or software control and normally run only when a message is to be printed.

The logging and report generation programs provide a high level language capability for describing headers and report formats, and for accessing data. The programming should also allow for describing when a report is to be printed and on what device. Typically, reports are initiated on the basis of:

- An operator demand
- A selected event
- A periodic clock such as, hourly, daily, weekly, monthly, etc.
- A specified time and date

6. Programmer's Aids

a. Standard Assemblers and Compilers

Provisions should be made for a standard assembler for the machines provided. The most recent version of a FORTRAN IV compiler should be considered. The compiler must be capable of interfacing with system I/O devices through software modules. Real-time and on-line operations of either machine should be affected by use of standard assemblers and compilers.

b. Data Base and CRT Picture Generation and Updating

Only a software system which permits a programmer or engineer to generate or modify the data base conveniently, or create or modify CRT pictures and establish the necessary linkages to the system data base and application programs without disruption of on-line operations should be considered. The data base and CRT picture generation and updating system should operate in an English language conversional

mode using the CRT displays and associated keyboards. The system instructions should lead the programmer or engineer through all necessary steps in making additions or modifications to the data base and/or CRT displays. Changes will normally be made on a backup computer, and when completed, implemented by an intentional failover to that machine. All operator or programmer action and entries associated with on-line compiling should be recorded in the form of an audit trail with CRT display and printout capability.

c. Utilities

A software system should be considered which aids the system programmer in creating new report formats or modifying existing report formats. Standard service and utility programs for on-line and off-line operations should be provided including routines for edit and debug, dump, maintenance, diagnostic, and loaders. It is also important to ascertain what affect the use of diagnostics have on normal real-time and on-line operations.

7. Application Software Requirements

All power application programs should utilize interactive CRT displays. All data entries should be checked for reasonableness, and error messages displayed when the checks fail. Except for time of day, quiescent system dynamic information on all CRT displays should be updated at least once every ten seconds. Alarm information should be displayed immediately.

Displays associated with the application programs should be directly accessible by function key, through an interactive CRT display, or an application display index.

a. System Display and Monitoring

CRT displays using multi-color, limited graphics capability generally serve as the primary medium for the operator to observe power system operation. The information is conveyed by various displays generally categorized by the following:

° System summary display
° Station one-line diagrams
° Station tabular displays
° Alarm displays

- Off-normal status displays
- Trend displays
- Configuration displays
- Utility displays
- Manually-entered data display
- Tagged device display
- Application displays.

Other forms of monitoring include panel-mounted chart recorders and panel-mounted digital readouts. In addition to standard handler software for channel assignment, drive, scale and offset, the capability should be considered for operator assignment, via a CRT display, of trend chart recorder channels and digital displays to any variable contained in the data base.

(1) System Summary Display

A system summary display should be provided which provides an overall view of present operating conditions.

Information on this display shall contain as a minimum:

- Total generation capability on-line
- Total generation
- Total system load
- On-line reserve
- Contol error
- System frequency
  - -actual
  - -scheduled
- Time error
- AGC mode
- Net interchange
- Net scheduled interchange
- Total inadvertent on-peak and off-peak
- Net interchange

(2) Station One-Line Diagrams

One-line diagrams are a virtual must in today's modern power systems. These diagrams shall contain specific real-time data and status information and are used in an interactive manner by the operator for supervisory control.

Dynamic information that may be included on a one-line display includes:

- ° Circuit breaker open or closed
- ° Disconnect switch open or closed (operator input)
- ° Device tag indication (operator input)
- ° Line flow and direction (MW and MVAR)
- ° Bus volts (kV)
- ° Data quality
- ° Transformer load (MVA - calculated)
- ° RTU "Local/Remote" status

(3) Station Tabular Displays

The tabular displays contain all dynamic and static information contained on each one-line diagram plus additional information. The additional information may consist of operational limits, reasonability limits, and normal status. These displays also may be used to inhibit scan of individual points and have indications available indicating a stop scan condition. These displays are used by the operator in an interactive mode to substitute quantities, set limits, set normal status, and for scan control. An area for station notes should be made a part of each tabular display. Narrative notes can then be entered by the operator using the keyboard and edit features of the display generators and entered into the computer memory for subsequent recall, modification, cancellation, or additional entry.

(4) Alarm Displays

A multi-page alarm display should be provided which displays the contents of the alarm file. When the alarm display is requested, the page containing the most recent alarm should be displayed. A single graphic character associated with each incoming alarm line should flash until the alarm is acknowledged. When alarms have been cleared, the alarm message may then be removed.

(5) Off-normal Status Display

An off-normal status display should be considered which indicates on a point-by-point basis, discrepancies between telemetered status points and normal status bits stored in the data base. The off-normal status display should be color coded to allow identification of abnormal states caused by an alarm action or supervisory control action. The display should automatically close up whenever messages are automatically deleted from the display by return to normal.

(6) Tagged Device Display

A display which lists all tagged devices should be provided. This display can be created by scanning the status points in the real-time data base for a tagged attribute. It is not necessary to maintain a special file for this function. Capability should be provided for printout of the contents of this display.

(7) Video Trend Display

In addition to conventional CRT displays for one-lines, tabular data, and special applications, a video trend display generator may also be provided. This capability permits up to four simultaneous variables to be plotted continuously against time to be displayed on each console.

This CRT display is particularly useful if it is desirable for the operator to:

- Select the desired variables from the real-time data base to be trended
- Establish a desired time baseline
- Establish scaling factors and offset
- Establish shaded areas
- Annotate video trending charts.

b. Supervisory Control and Tagging

Supervisory control occur via operator interaction with a combination of interactive CRT display and/or function keys. Two types of displays may be provided for supervisory control interaction: one-line diagrams and station tabular displays. The control and

interaction philosophy is the same with each type display, except that the station tabular display includes certain features not available on the one-line diagrams.

Supervisory control involves a "select-before-operate" sequence. The preferred steps in performing a supervisory control action are as follows:

- Select the desired station one-line diagram or station tabular display
- Select the device to be controlled by placing a cursor or light pen on the symbol and actuating a select function. Visual verification of this step should be provided. If the next step is not made within a prescribable period, the selection is automatically cancelled
- Select the appropriate TRIP/CLOSE poke point indicator on the CRT display or function key. The computer then addresses the appropriate RTU where the message is decoded and the individual control relay is selected. The RTU will then send a checkback message to the computer containing the identification of the control point. The computer, after verifying the validity of the checkback message, automatically issues the execute command
- Upon successful completion of the operation, a positive acknowledgement is provided. If not, an alarm is activated
- A CANCEL function is provided to allow the operator at his discretion to disengage the operation prior to executing the command.

All executed supervisory control actions are printed as they occur on the operator action logger and stored in a history file for later use in a station activity report. Each action is identified with the time of occurance in month, day, hour, minute, and nearest two seconds, station name, device name, and ID number, originating console ID and action, such as TRIP or CLOSE.

An indication is provided on all CRT displays associated with supervisory control to show RTU LOCAL/REMOTE switch position.

RAISE/LOWER control capability for future transformers should be provided and implemented in a manner similar to TRIP/CLOSE. For each RAISE or LOWER command a single timed relay closure occurs at the selected RTU. Reselection of the point is not necessary for successive commands which occur before time out. A CANCEL function may be provided to disengage the operation at the operator's discretion.

Other forms of required control action requiring software in the initial system include:

- ° <u>kWh Freeze Command</u> - Which, on the hour is transmitted to selected RTU's causing kWh accumulating registers to freeze

- ° <u>Generation Raise Lower Pulses</u> - Which is derived from the AGC program and are of multiple duration

- ° <u>Telemeter Calibrate</u>

Checkback is not required with these control modes.

The system should be able to change the state of silent devices through a supervisory control action. The system should also provide the capability to manually change the state of a point that is out-of-scan.

A simple form of device tagging should be provided. This function is closely related to supervisory control and utilizes the station one-line diagrams and the station tabular displays in an operator interactive manner.

Clearance requests and other specific information related to the type or purpose of the tagged condition is stored by the computer. Tagging shall be accomplished by positioning the cursor on the station tabular display over the desired device, entering a reference number and depressing TAG. Removing a tag is accomplished by positioning the cursor on the station tabular display over the desired device and actuating REMOVE TAG. Any supervised device which has been tagged is inhibited from any supervisory control action. Each tag or tag removal action is printed on the operator action logger, showing date, time of day, action taken, station, point ID, and

reference number. Capability should be provided to tag devices which are not supervised or which may be at a station with no RTU. Any power system device which has been tagged must appear in a tagged state on any display showing that device.

c. Limit Checking, Status Checking, and Alarming

(1) Limit Checking

Specified measurements or other variables should be tested against stored limits periodically or under program control. Limit files are stored where limit data is used in routine or special application tests. The contents of all limit files should be available for display on the station tabular CRT displays with the capability for change by the operator. An alarm is generated and logged whenever and operating limit is exceeded.

Reasonableness limit checks are applied to all manually entered data or to data where operating limits have been exceeded. These include high, low, sign and non-numeric checks. They define the possible outside limits for each measurement based upon physical restrictions. If a reasonableness check fails following manual data entry, an error message is generated and displayed indicating the general nature of the failure. Reasonability limit magnitude and sign values are independent of operating limit magnitudes and sign values.

(2) Status Checking

The status of all devices or conditions which can be one of two states is checked against stored normal status. Two states, typically OPEN or CLOSED, are stored and compared with status points for detection of off-normal states. The normal state of each device is stored in a file and made available on the station tabular CRT displays.

(3) System Alarming

It is necessary to monitor selected analog and status points for alarm conditions. Certain application programs may also produce alarms. An

alarm should be generated, stored in the alarm file, and printed if any of the following conditions occur:

- An unauthorized change of status is detected
- An operational or reasonability (high or low) limit is exceeded
- Error thresholds are exceeded
- A supervisory controlled device fails to operate
- An RTU fails to respond correctly
- Failure of selected ECS hardware
- When requested by an application program

Two alarm classifications are generally provided; critical and non-critical. Classification of alarms are assignable as part of the data base compilation procedure. Critical alarms are those requiring immediate operator attention and acknowledgement. Non-critical alarms are brought to the attention of the operator but immediate operator reaction or acknowledgement is not required.

An alarm file should be provided for the storage of up to 150 alarm messages. The alarm program assembles each alarm message from a combination of telemetered information and stored message elements. Each alarm message contains the following information as a minimum:

- Date
- Time of day - hours, minutes, seconds
- Station ID where alarm occured (four-letter minimum)
- Device or measurement name and ID (four-digit minimum)
- Nature of alarm such as TRIP, CLOSE, HIGH,
- LOW, RTU, FAILURE, etc. along with an English language narrative description
- Sequence of events, where available, such as close/trip/close
- Stored analog limit and actual value which produced alarm

Information contained in alarm messages need not be updated by subsequent scans after the message is stored. Status and event (TRIP/CLOSE) alarms may be stored in the substation activity file for

report generation. Whenever an alarm occurs, the following should occur:

- An Alarm message is composed
- The alarm message is stored in the alarm file and be presented on the alarm display
- Audible alarms occur as follows:
  - (a) A repeating two-tone alarm for critical alarms
  - (b) A non-repeating tone for non-critical alarms
- The alarm message is printed on the alarm logger
- The device symbol on one-line diagrams and the analog or status point on a station tabular display shall blink

When a critical alarm occurs, it is acknowledged by the operator. A symbol by each unacknowledged alarm blinks on all CRT displays. Acknowledgement shall cause unacknowledged alarms to cease blinking, return-to-normal alarms to clear from the file, and silence the audible alarm. Non-critical alarms should be automatically acknowledged by the system after two seconds if operator acknowledgement has not occured.

Additional required features of the alarm program include:

- Flashing red represents unacknowledged new alarm, solid red represents acknowledged alarm and flashing white represents and unacknowledged alarm returned to normal state

- Audible devices may be silenced either by an "Alarm Silence" or "Alarm Acknowledge" function key. Alarm Silence should not acknowledge an alarm but shall only inhibit the audio device. A subsequent new alarm should cause the alarm chime to sound. An alarm chime "Inhibit" function should be provided which allows the operator to silence the chimes completely

- Capability to acknowledge alarms individually or to acknowledge all new alarms simultaneously from the alarm page. Operator acknowledgement of an alarm(s) logged

out on the operator action logger

- Alarm messages may be arranged in chronological or reverse order on the CRT; however, the page with the latest alarm is always displayed when the alarm list is requested

- An alarm message should remain on the alarm summary until the operator has subsequently acknowledged the return-to-normal alarm condition or subsequently chooses to delete the alarm

- When an alarm point returns to its normal state another alarm message (in white) is generated. When the operator acknowledges the return to normal condition all messages pertaining to the particular alarm are removed from the system

- Blocking of alarms should occur when: (a) a status or analog point is taken off scan, (b) when limits have been removed, or (c) the alarming of a point has been blocked

- If the alarm file becomes full, new incoming alarms should continue to be printed of the alarm logger

- Prior to the file becoming full the operator should receive an alarm of the pending condition. He should also receive an alarm when the file is full

- The alarm logger should print each alarm message as it is available and alarm return-to-normal conditions when they occur. The operator action logger records all operator action pertaining to alarm actions performed by the operator

(4) <u>Required Program Inputs</u>

Information inputs to the alarm program shall be:

- Time and date
- Status points
- Analog points

- Supervisory control program
- Normal state conditions
- Alarm classification
- Operator action
- Alarm blocking conditions
- Function keys

(5) <u>Program Outputs</u>

- Alarm messages on the alarm logger (English language)
- Alarm messages to substain activity file for status and TRIP/CLOSE events
- Alarm messages on the appropriate CRT displays (English language)
- Operator action logging of alarm acknowledgement and deletions
- Audible alarms

(6) <u>Displays and Operator Interaction</u>

The following interfaces are provided for alarm control and status by the operator:

- <u>Interactive CRT displays</u>
  Any CRT picture where alarmed point is displayed
  Alarm summary display
  Dedicated critical alarm messages on every display

- <u>Printing Devices</u>
  Alarm logger
  Operator action logger

- <u>Audible Devices</u>
  Repeating stroke two-tone chime for critical alarms
  Single stroke chime for non-critical alarm and return-to-normal

- <u>Function Keys</u>
  Acknowledge
  Inhibit (chime)
  Silence (chime)
  Delete

(6) Program Execution

An alarm program operates in a variety of modes. Execution of each mode normally occurs from one of the following sources:

- ° Automatic detection of an alarm condition
- ° Automatic return of out-of-limits conditions
- ° Operator inputs-requests

d. Teletype Communication

Programming should be provided for a teletype network communications program which shall permit the operator to compose a preformatted message, and when correct, transmit the message via an existing teletype network by operator demand or when polled.

In addition to the preformatted forms a free-form message capability should also be provided. The free-form display should include provisions for addressing the message to individual stations, groups of stations or broadcasting the message to all stations. Logic and buffering should be provided to handle messages to stations which are busy and require delayed transmission.

Data input requirements for the teletype program are:

- ° Real-time System Inputs
    - System time and date

- ° Manually-Entered Data
    - Values and narrative text
    - Text editing
    - Operator selection of addresses
    - Transmit command

Teletype network message input displays should allow the operator to input preformatted message data to the system.

The operator should be provided with the following interfaces:

- ° Interactive CRT Displays
    - Preformatted message pages (2 minimum)
    - Narrative message pages (2 minimum)

° Printing Devices
  Operator action logger
  Line printer (alternate destination)

e. Log and Report Generation

Alarms and operator actions are printed by the character printers. One printer shall normally print alarm messages and the other operator action information. Another printer may be used with the programmer's console and may serve as a backup for the other logging printers. The printer motors start and stop under software control and will normally run only when a message is to be printed.

Complete programming should be provided by the vendor for the logs and reports listed below. All logs and reports should include the date and time of printout and the date of the data contained within the report.

(1) Logs

Capability should be provided to automatically generate the following logs:

° Alarm Log - Printed as alarms occur. Data be arranged and formatted by the alarm program and stored in the alarm file

° Operation Action Log - Printed following each operator control or data modification action. Examples include all supervisory control action, data substitution, alarm delete, and operator notes. All data for this log is formatted and arranged by the originating program. All outputs to this logger are time tagged

(2) Reports

Capability should be provided to generate reports automatically following each 24-hour period or by operator request. The reports to be generated are:

° Hourly Net Generation Summary - This report shows hourly net MWH for all major units and station totals for smaller stations

- Scheduled Interchange Summary - This report shows the hourly scheduled in and out energy and type of interchange over a 24-hour period with each interfacing company. The type of interchange is also identified

- System Load Summary - This report provides a summary of system load on an hourly basis including generation, metered intertie, scheduled intertie, inadvertant, on-line reserve, off-line reserve and capacity down for maintenance

- Actual Interchange Summary - This report shows actual interchange on an hourly basis between utilities

- Tie Line Summary - This report will provide a record of actual hourly flow, in and out, over all metered intertie points

- Operator Message Log Summary - This report will show the contents of all operator stored messages

- Communication Channel Error Summary - This report is derived from the alarm file and shall summarize all channel failure conditions or excessive channel dropouts. In addition, this report summarizes all analog channel failures (backup values via local RTU) and communications alarms

D. Man/Machine Interface Requirements

This section examines the man/machine interface features to be considered for incorporation into the control system design. Man/machine subsystems provide the means for System Dispatchers to communicate with the computer system and to access power system data. The System Dispatcher positioned at his console during normal, emergency, or restorative system conditions, must reach decisions critical to the power system. The validity of the results is directly related to the conciseness and logical form of the information. In many instances, rapid access to a complete picture of the prevailing conditions in the power system is critical. Electric system Borrower Dispatch Personnel need modern man/machine interfaces to support these operational requirements. This section presents a discussion of man/machine facilities which are convenient and cost-effective.

The man/machine equipment must satisfy immediate needs and future expansion requirements. A compromise acceptable at installation time which does not adequately satisfy future needs, only defers operational hazards and substantially increases the long-term costs of the project. Generators, substations and sub-transmission lines that strengthen the power system are being added regularly. Anticipation of this normal growth in the system, as it relates to man/machine interface design, will ensure continuity of reliable power system operation. The description of the System Dispatcher console, which is the focal point of man/machine interface, considers these requirements.

1. CRT-based Interface

Modern control systems utilize the CRT as the principle man/machine interface. The CRT's versitility provides solutions to the many requirements of a System Dispatcher. Utilizing both alphanumeric tabulation formats and schematic or "limited graphic" formats, the CRT subsystem can reinforce data presentations, dynamically focus the Dispatchers with a compact and powerful operational interface, while maintaining a large capacity for expansion. Additions to the power network system control functions can usually be performed without physically altering the CRT man/machine interface.

The data sorting and organizing capability of the computer allows logical formating of system data required by the Dispatcher. CRT display units are available with seven-color displays, including alphanumeric and schematic formats. State-of-the-art CRT display units and driver software permit status and control points to be organized on single-

line substation CRT displays with dynamically-updated telemetered values such as, MW, MVAR and KV. Functional groupings of many of these same data quantities on other displays more readily facilitates monitoring and control. This flexibility accommodates a virtually limitless repertoire of functional data presentations viewable through a common display subsystem, and fosters the use of the CRT as a focal point for display of power system information. CRT features such as character blinking, color change, color inversion, underlining and special symbol annotation also direct Dispatcher attention to particular categories and changes of system data.

a. Expansion Capabilities of CRTs

To add new displays, new analytical programs, new equipment, or substations to a CRT-based SCADA system, requires only internal changes and additions. The external physical appearance of the system should remain unchanged throughout its life. Thus, no new steelwork, floor space or functional change is required to respond to normal system growth. It should be noted however, that the ability of the CRT-based system to grow is dependent on carefully designed growth capabilities. The future must be sufficiently described on carefully designed growth capabilities. The future must be sufficiently described in the specification to allow the Vendor to size main memory, auxiliary memory, computational and channel capability to absorb all known future needs with a healthy safety factor. The software structure should be sufficiently modular and parameterized to permit future growth with a minimum of disruption. The state-of-the-art in CRT updating (i.e., the building, integration and activation of new alphanumeric and one-line displays) has responded to the need of the users to make necessary changes and additions on-line, with no interference to critical functions.

The CRT-based system will require a small functional pushbutton panel and keyboard. Pushbuttons will perform control actions, initiate functions, and call for index displays. The keyboard, similar in design and function to a standard typist's keyboard, will be used for Dispatcher entry of numeric values and repetitive alphanumeric messages. The ability to build a new display and include it on a general index display for its category allows the Programmer/Engineer to expand any existing function to the limit of main and auxiliary storage available. Spare pushbuttons allow the Program-

mer/Engineer to include completely new functions.

b. Responsiveness of CRT-based Systems

As opposed to the dispersed nature of traditional hard-wired masters, the CRT represents a highly concentrated form of man/machine interface. Physical movement of the Dispatcher is minimized, the data he requires is in front of him, either automatically, or on demand. The greater the variety of the information he requires the greater the efficiency of the CRT approach becomes. Control actions can be performed on the CRT with the insertion of new parameters on the same display on which related data is displayed. Related data includes overviews, one-line diagrams, and study outputs. The ability of the CRT to provide all of this data swiftly must increase the overall security of the electrical system.

2. Representative Alphanumeric CRT Displays

One of the advantages of a truly flexible CRT system is that it is in no way bound by the manufacturer's standard displays. Dispatchers can incorporate any display based on data existing in the system data base. If the data does not exist in the data base an appropriate analytical program must be written to provide it.

The CRT subsystem will be the heart of the man/machine interface. The CRT displays will allow the dispatchers to view any pertinent information, and to make required entries, as well as allow the programmer to maintain the software system.

A parameter of vital importance to the performance of the system is the time required to respond to an operator request for a display. The average response time to display requests should be no less than one second, and no more than two seconds with heavy system activity occuring. This response time is the critical measure of how much the control system will be of aid during system disturbance.

All displays, alphanumeric and graphic, will include some common attributes. Fixed fields will contain time and date information, the display title, and, for multiple page displays, a page number. Each display should include a 'scratch pad' area, allowing special purpose messages or

tag information to be added on-line. As an adjunct to the scratch pad, dedicated alarm lines common to all displays should be provided to display a small number (two to five) of the latest alarms. When an alarm occurs, the Dispatcher can determine the alarm's location, normally via a short acronym, and, by cursor selection, call up the one-line of the alarming RTU. The following briefly summarize some typical display types:

- Index Displays. A tabular listing used by the System Dispatcher in lieu of pushbuttons to select substation displays. The Substation Index Displays obviate the need for display selection hardware, and simplifies additions as new substations are added to the power system. Additional Index Displays will be provided for other categories of displays, such as generating stations and system logs

- Substation Display A switchyard may be used as an example of an alphanumeric display to present data, and to input monitoring parameters. The Dispatcher may enter high and low limits, status and other parameters, and note the actual MW and status of equipment

- Generation and Load Summary A tabular listing of summary data relating to generation and load as well as individual Generation Units. It should include telemetered data and calculated values such as capacity and available reserve

- Event Display. The Events Display allows the Dispatcher to view a copy of the "N" most recent messages. The display is "rolled" - i.e., new events are added at the top of the page as they occur, the existing data are bumped downward, and the bottom most ("Nth") entry is deleted. All system events, including alarms, Dispatcher control actions, and control system status messages, are included on this display

- Off Normal Display All active system abnormalities and alarms are included on this display. Data displayed includes the time of the event, a priority or type message, the name of the RTU location, device location, device number, and a description of the abnormality. Key to the understanding of the display is the definition of "ALARM" and "AUTH CHANGE". An alarm is an uncommanded change of state or a limit

violation. Alarms will be displayed until they have been acknowledged and have returned to normal. An Authorized Change (AUTH CHANGE) is a change of state caused by Dispatcher action. Authorized Changes will be displayed as long as the resulting status differs from a predefined 'Normal' state. The Off Normal Display serves as an alarm summary, and a description of system operation differing from the norm

- Load Shedding. This display provides a listing of loads to be interrupted during an emergency. The list should be updated periodically. The System Dispatcher may initiate control from this display. Optional supporting programs can be provided to track outage time and alert the System Dispatcher to transfer outage to the next scheduled group.

- Interchange Schedule A listing of all scheduled interchanges, active and pending, is maintained on this display. The Dispatcher can enter negotiated transactions in advance of their scheduled initiation, and utilize the computer to activate, end, and log the interchange

- Tagging List This display will list all the devices currently in a tagged condition, along with pertinent information about the tag including time, date, and reason for the tag. When a device is tagged (via the station display) the pertinent information will automatically be entered on the tagging list display, and two lines will be available for free-form messages to be entered by the dispatcher. Tags may only be removed via the tagging list display. Multiple levels of tagging will be supported by the system, and the software will be designed to provide as much security as possible,to prevent inadvertent removal of tags

- Alarm Lists The alarm lists are the means of presenting alarms to the dispatchers. Acknowledged alarms would be distinguished from unacknowledged alarms. An abnormal summary would list all devices that are in abnormal conditions. This would include analog values that exceed their limits. The occurence of one or more alarms will not restrict the dispatchers from viewing any displays

° Generation Dispatch Displays: These allow the dispatchers to monitor and enter pertinent information about the generation dispatch function. Interchange schedules, as well as generator control information, such as unit operating mode, are dealt with in these formats. The AGC capability functions will be procured, but not used initially. The feature will be available to be "passively" used by the dispatcher

° Master Station Status and Control Displays: These displays would show the configuration and status of the hardware system. This includes the configuration and assignment of the computer systems and peripherals

° Scratchpad and Message Displays: These formats allow the dispatchers to make free-form entries on the CRTs. These might be messages to the next shift, or trying out new display formats to be implemented by a programmer. There will be a field on the station displays to indicate whether there are any messages relevant to that substation

° Static Displays: These displays contain no variable data on them, and are for informational purposes only. Switching information or other procedures might be summarized on the static displays

° Miscellaneous Functions: Various other functions such as trend recorder pen assignment, or RTU communications and scan control, would be carried out by displays accessible to the dispatchers

° Log Formats: The data for the periodic logs may be reviewed and altered via the Log Format Displays. These logs include those that are output each hour, as well as those that appear once a day

° Programmer's Formats: The Programmer's formats allow those functions that are performed by a programmer, or other trained person, to be accomplished from a console, using the CRT display system. These functions include:

Data Base Editing
CRT Display Format Editing
Utility Functions
AGC Performance Tuning (when AGC is used)

3. Representative Limited Graphic Displays

Some data favors a tabulated alphanumeric display such as those listed in Section 2. Limited graphic capability adds another dimension to CRT monitoring and control. The immediate availability of the visual image of a one-line diagram eliminates the necessity for most loose-leaf books, drawings or other extra-computer references. The tools of the Dispatcher's trade are directly in front of him, available at the push of a button and the movement of a cursor. Dynamic schematics of substations are particularly useful when a direct control action is required. All stages of input, verification, equipment change, and data values are dynamically displayed. Although limited graphic CRTs with color capability do represent added system expense for both hardware and software, the added cost is small considering the technical advantages.

A heirarchial set of graphic displays, linked to corresponding alphanumeric displays, is recommended. The Dispatchers should be provided with displays which provide a quick overview of system status, and which serve as indices into more detailed displays showing all system data. The following is a representative display strategy:

> Bulk Power Diagram: This display has the attributes normally associated with a dynamic mapboard, and also serves as an index to substation displays. It can be segmented into several displays to fit a CRT. Each display will cover a geographic or operating area. Interconnections among the segments will be shown, and segments can be called one from the other through cursor selection. Initial selection of the desired segment of this diagram can be accomplished through use of dedicated pushbuttons, back-lighted, and/or flashing to indicate the presence of an alarm, or through an index block diagram and cursor-sensitive points. The Bulk Power Diagram would have the following attributes:
>
> - Substations will be represented by squares annotated with the substation name or a special symbol
> - Flashing of the symbol representing the facility will show substation alarms and circuit tripping
> - Selection of a substation block will result in the display of the substation diagram of that

particular station

Substation Displays: These displays will have the following characteristics:

- Status of all monitored devices will be dynamically updated
- Status of any non-monitored devices will be entered by the System Dispatcher
- Analog values will be dynamically updated when shown
- All controllable devices, including tap changing transformers may be controlled from this display
- Alarms associated with this display may be acknowledged from this display

4. Console Configuration

Efficient interaction between man and machine, and expandability that parallels power system growth, is the major objective of the console design. Communicating with outlying districts and other utilities, preparing reports, executing switching orders, monitoring power system performance, and executing control actions, should be considered in the overall design. Access to frequently used devices should be convenient. Consoles should be compact and expandable. Sight paths to non-console mounted devices such as wall mounted recorders and indicators should not be obstructed by the consoles.

Control center designs typically provide a minimum of two or three operating positions:

- Dispatcher - used for normal operations
- Second Dispatcher - used only during stress conditions
- Programmer/Engineer/Training (P/E/T) - used for off-line and background functions, available for engineering use during stress situations

The two Dispatcher stations should be located on the operating room floor, while the programmer position may be located in the computer equipment room.

The minimum acceptable configuration for the consoles would be two, two CRT consoles, one utilized as a Dispatcher Console and the second as the Programmer/Engineer Console.

The following paragraphs describe the design and function of a Dispatcher's Console and a Pragrammer/Engineer Console, utilizing a two CRT console and a single CRT console respectively. To make this configuration viable, the optional Keyboard/Function Panel or a third two CRT console would be required.

a. System Dispatcher Console

One operating console would be provided for the System Dispatcher's interface to the ECS. The console would contain two CRTs, with a function pushbutton panel, cursor control, and keyboard, located directly in front of and below the CRT faces. The characteristics of the Vendor's standard equipment will have a significant effect on the final arrangement of the console, but it should be designed to allow two men to operate it in an emergency.

Telecommunication equipment will be provided in the form of an integral "Call Director" dial system, mounted on the console. The equipment will be configured to allow use of a conventional hand set or a lightweight headphone at the Dispatcher's discretion.

The console should be rigidly constructed to provide adequate workspace for Dispatchers, storage space for books and reference material, voice communication facilities, calculator, and drawer space. Writing areas should be scratch, glare, and burn resistant. Lighting reflections from CRT screens and other working surfaces are unacceptable. The project staff will be required to coordinate the console design with the facility architect to ensure adequate lighting levels on work spaces without inducing glare on the CRT displays. A Dispatcher's movements between telecommunication facilities, CRT, keyboard and writing surfaces, should be unimpeded by vertical supports.

b. Programmer/Engineer/Console

A second console will be provided for use by the engineering staff. The equipment will be identical to the Dispatcher Console, with one CRT and one function panel

and keyboard located directly below the CRT screen.

The control system engineers will be adding new RTUs, modifying CRT formats, and incorporating new functions on a continuing basis, throughout the life of the system. Time for design effort, testing, and changes will be reduced to a minimum with properly implemented support resources. The console will be used to build CRT displays, add to the system data base, test new application software, and will be used extensively when testing new remote terminal units or point additions. The panel and CRT are necessary to simulate System Dispatcher interaction before activating additional programs for normal on-line use.

Preventive maintenance, and rapid correction of random system malfunctions require a comprehensive maintenance facility. The Programmer/Engineer/Training facilities will be used to initiate on-line and off-line diagnostics and monitor normal operation, and can be used as an operating console in emergencies, or when the Dispatcher Console is down due to equipment failure.

The Programmer/Engineer Console will be functionally identical to the Dispatcher Console and can be used for System Dispatcher training. The trainee can execute all normal operations such as initiating control, changing limits, reacting to simulated alarms, and other normal functions. While in training mode, the real-time system will be protected against inadvertent control of actual system points. This console could also be used as a public information vehicle for visitors.

5. Alarming

Although both CRTs at a console station are interchangeable, it is expected that one CRT will normally be assigned as the Off Normal display. Particular care should be exercised in designing this display which will be used continuous use. Alarms should be divided into three priorities: (1) class 1 alarms (high priority electric system alarms), (2) class 2 alarms (low priority electric system alarms), and (3) general computer system alarms. CRT and logger messages should indicate the priority of any alarm.

Associated with the Off Normal Display are two alarm devices. A single-stroke audible alarm,and a console light. On the occurence of a new alarm the console light will be switched on. The single-stroke audible annunciation should be activated only upon the occurence of class 1 alarms. A new alarm should also appear flashing on the CRT screen. The console light remains lighted until the alarm is acknowleged. The new alarm message appearing on the CRT will turn steady. The only method by which alarms may be removed from this display, is by elimination of the alarm condition itself. Alarm messages appearing on the CRT should be "acknowledged" by use of the cursor and input capabilities of the CRT. If the space allotted to alarms is insufficient to hold the full set of undeleted alarms, the condition should be indicated at the bottom of its section, and a method provided to call up additional pages to display all current alarms within the alarm buffer. A history of alarms should be printed on the system alarm as they occur, and will also be retained in the Events Display until displaced by subsequent events.

In addition to the undeleted alarms contained on the CRT, the display should also include status conditions which differ from their predefined "normal" state (i.e., a breaker which has been commanded open for line maintenance). The Off Normal Display may be used by Dispatchers at the changing of shifts, to provide a easily understood description of the current state of the power system operation.

6. Recording and Indicating Devices

Chart recorders and analog indicating meters are often utilized by the System Dispatcher as the primary method of monitoring important system parameters, and for historical record purposes. If this procedure, however, is carried to an extreme, it results in so large a number of devices that it is impossible to assimilate the information provided. It is recommended that a small number of these devices be incorporated for critical parameters. Other values may be viewed on the CRTs. If hard-copy or continuous viewing of a particular parameter is required, the variable may be assigned to one of several recorders.

The dedicated strip chart recorders should monitor critical system variables. These recorders should be located adjacent to the console to provide easy viewing by the System Dispatcher.

The system requirements may also call for recorders for Dispatcher-designated trending purposes. This allows the System Dispatcher to observe long-term trends, and to analyze in detail, a short-term phenomenon. Any telemetered point and/or calculated value in the data base may be designated for trending. The System Dispatcher should have a convenient means to designate points, delete points, select time intervals and scaling, and to designate recorder channels. A CRT display will be used to specify the assignment and the range of the recorder scale. Once this data is entered by the Dispatcher, this display will retain the information until changed and serve as a legend to identify various charts to other System Dispatchers, or to refresh the memory of the System Dispatcher who initiated the request.

7. Printing Devices

The system should include provision for printers to provide hard copy records of a variety of system events. There is the need for two printers as follows:

- Events Printer: System events, alarm messages, operator console actions, etc.

- Reports Printer: Reports generated by application programs and resource utilization programs

These printers should be located away from the vicinity of the consoles to reduce the noise level in the immediate area of the Dispatcher. The Events Display can be used by the Dispatcher to examine recent events, thus removing the need to have the printers in proximity to his normal station. A high speed line printer will be located in the computer room for use by programmers during the assembling and compilation of new programs. It may also be used as a logging printer if the particular report is not directed to the System Dispatcher. Software used to drive printers should be general purpose and be capable of directing reports and messages to a designated back-up printer if the normal unit fails.

8. Expansion Capability

The computer system must satisfy both immediate man/machine interface requirements and the projected needs of the power system. The flexibility of a computer-based CRT system inherently satisfies these requirements. Expansion

is achieved by enlarging the computer system data base and adding new, or modifying existing display formats. Physical change of the man/machine interface is avoided by utilizing existing CRT screens. This flexibility does not, however, preclude additions to the physical resources of the system. New CRTs may be added, new functions augmented, or existing functions subdivided. Console steelwork construction should be modular and floor space allotments must anticipate growth.

Identification of future requirements is necessary so that the Vendor may initially configure his system for probable expansion in main memory, auxiliary memory and I/O channel capability. Software architecture must be sufficiently modular to facilitate additions without major disruption, or costly restructuring of the initial system. All changes should be made on-line without interference or risk of outage of the existing system.

E. Facility Requirements

This section provides for consideration in planning control system facility. It is intended as a guide, presenting only the requirements for housing the control equipment and directly related personnel. Some Borrowers have experienced reduced control system availability and maintenance difficulties due to insufficient space allocation, power system supply, and environmental control equipment capacity. The descriptions presented here are representative of typical installations developed from an analysis of the characteristics of other control centers. The final building configuration must also include normal architectural and safety considerations. Consultation with personnel responsible for building architecture, equipment suppliers, and staff engineers will be necessary, to prepare detailed specifications for lighting, acoustics, fire prevention, security systems, air conditioning, uninterruptable power supplies, and electrical interference. Four general topics are discussed in the following paragraphs: (1) physical characteristics, (2) security, (3) environmental characteristics, and (4) power conditioning.

1. Physical Characteristics

This section will describe the various rooms required in the control center, their approximate size and relationship to one another. Five areas of the facility have been identified: (1) System Control Room, (2) Equipment Room, (3) Programming Facility, (4) Office, Maintenance and Storage Facilities, and (5) Power Supply Area.

Important considerations include plans for moving new equipment into place and the free movement of maintenance equipment and supplies inside the various areas. At least one set of high double doors with outside access should be considered. The most severe moving problems to be anticipated will involve the transporting of multi-bay electronics racks which cannot be tipped substantially off the vertical.

a. System Control Room

The system control room contains the dispatcher control console, system mapboard, printers, recorder boards, and a small amount of interface electronics. A minimum area of 42 sq. meters will allow adequate space for a single dispatcher console, and an optional second console, loggers, and a conference/work table. A high ceiling (3.7-4.6 m) may be required in this room if a system mapboard is included. A false flooring of .6x.6 m removable panels, .3 meters high, should be provided throughout this area to support equipment, and allow hidden routing of electrical cables. The distance of computer driven equipment from the equipment room should not exceed 46 meters (60 cable meters).

b. Equipment Room

The control computers, input/output interfaces, and the bulk of the auxiliary electronic equipment will be located in this room. A 90 square meter area with a 2.7 meter ceiling, is adequate. The shape of the room is not critical. It is advisable to allow a generous margin for future expansion in these rooms. Working space (desks and/or tables) for two programmers/engineers should be available in this room. A one foot high false flooring of .6x.6 m removable panels is needed throughout. The computer room need not be located at the same level as the control room. However, it should be in proximity to the control room to minimize cable lengths. Cable troughs should be provided, to allow routing of cables between the two rooms beneath the false flooring. To facilitate environmental control, this room is usually located in the center of the building. When located on an exterior wall, suitable insulation must be provided to permit close control of temperature and humidity.

c. Programming Facility

The purpose of the programming facility is to provide a convenient location where new programs can be assembled, compiled, debugged, and integrated into the system, new applications can be formalized by engineers, and system dispatchers trained. The area will be used to modify existing functions or add new functions to the system.

The facility should contain a Programmer/Engineer/Training Console. Visual access to the system control room is necessary, if the console is to be used as a second dispatcher console during stress periods. Access to the control room and computer peripherals is required. Approximately 17 sq. meters of space will be required.

d. Office, Maintenance, and Storage Facilities

It is recommended that all system control personnel have their offices near the control center itself.

The allocation of maintenance areas depends heavily on the relative arrangement of other control center rooms. A minimum of 18 sq. meters is recommended. The final arrangement should provide for rapid movement of test equipment from the maintenance area to the equipment room.

Three types of storage facilities should be considered. These could be combined into a single room, or divided into separate areas. They are: (1) spare parts, (2) consumable supplies such as printer paper, chart paper and ribbons, and (3) protected storage of source programs, data, etc. Spare parts should be stored in closed containers - e.g., utility cabinets, in the maintenance area. Consumables can be stored on open shelving, or stacked on the floor on shipping pallets. An additional 5 sq. meters of floor area will be adequate for this function. Protected storage should be fireproof and tamperproof. Individual safes may be used, but because of the variety of shapes and sizes of computer records, a single vault with appropriate racks, files and shelves, is preferable. Approximately 5 sq. meters of floor area should be provided for this function.

e. Power Supply Area

The uninterruptable power supply and other power conditioning equipment require a separate area. A minimum of 14 sq. meters is required for the battery, charger, and inverter. This equipment should be sound isolated because of inverter hum, and located in an air conditioned portion of the building. OSHA requirements must be met in storage battery areas including venting and eye-wash facilities. A back up motor generator set and electrical switchgear could also be located external to the building. Such equipment should be isolated from the electronic equipment areas because of possible noise, vibration, and electromagnetic interference. The required floor space will depend on a detailed analysis of total facility power requirements.

2. Security

Two aspects of the security are discussed in this section: (1) access to the area, and (2) smoke and fire protection. The facility should incorporate sensors providing warnings of all types of violations to area security and their location.

a. Area Access

The control center contains valuable and vulnerable equipment which must be protected from intentional and accidental abuse. The tasks being performed by the system dispatcher necessitate protection from unnecessary distractions caused by unauthorized personnel in this area. For these reasons, access to the control systems should be restricted. A single entry point with cipher/key lock or under the control of the system dispatcher is recommended. All other doors to the facility area should be sealed in conformance with local fire regulations. It would also be advisable to sense the status of these doors, and trigger an alarm when one of them is opened.

b. Smoke and Fire Protection

The smoke and fire protection system performs three principal functions: (1) early detection of fire, and delivery of a warning to employees so that an attempt at hand extinguishing can be made, (2) detection of an advanced fire condition and automatic extinguishing,

and (3) warning to employees to evacuate the facility. Smoke and fire protection for the equipment area is particularly important during off-hours, since they may be out of view of control room personnel. The details of the final system depend on the architectural characteristics of the building. The National Fire Code and local fire and safety regulations may be consulted to determine specific design criteria.

Early detection of fire can be accomplished by a variety of smoke detectors. The bulk of these should be located below the false flooring where computer room fires most often originate. Some may also be located above floor level. Smoke detection should sound a distinctive alarm and give a clear indication of the location of the activated sensor. Hand fire extinguishers should be located throughout the area according to local codes. The smoke alarm should also sound in the control room.

The detection of a general fire condition is usually accomplished with thermal sensors located in the ceiling. These sensors should trigger a fire extinguishing system in the area in which the fire is sensed. The fire alarm should trigger an evacuation alarm within the facility and, if permitted, automatically alert local fire authorities.

3. Environmental Characteristics

This section describes the environment suitable for the equipment and personnel of the control system. The following topics will be discussed: (1) air conditioning, (2) acoustics, (3) lighting, and (4) electrical interference.

a. Air Conditioning

Severe air conditioning demands are made by the computer room equipment. This type of equipment is sensitive to humidity deviations and static charges accompanying low humidity. Computer manufacturers typically claim broad limits over which their equipment will operate satisfactorily. Experience has shown, however, that availability of computer equipment suffers appreciably, when even small deviations from nominal values occur. The computer room environment should be rigidly maintained. Consideration should be given to establishing some level of redundancy in the air conditioning

system to avoid heat excursions in the event of loss of a single unit.

It is recommended that separate air conditioning units be utilized to maintain the equipment room at 22 $\pm$ 1°C and 50% $\pm$ 5% relative humidity. The load will probably not be uniformly distributed throughout the room, so that provision must be made for directing the flow of air to high heat concentrations. The use of the under floor space as a plenum is one approach to this problem. A positive pressure should be maintained in the room, using filtered air to avoid excessive dust and dirt.

The power supply room is a relatively small room with high heat loads. Dissipation of approximately 40,000-70,000 BTU/Hr can be expected. The load is predominantly sensitive to heat. Temperature control can be somewhat relaxed from other areas with 18°C to 27°C being acceptable. Humidity control is not critical.

The remainder of the control system can be controlled by conventional means. The control requirements are dictated by personnel, rather than equipment needs (22° $\pm$ 1°F and 40% $\pm$10% relative humidity).

b. Acoustics

In areas where professional personnel are working, interior building materials should be selected on the basis of sound attenuation characteristics. Carpeting throughout the facility provides an additional source of sound attenuation. A goal of 50 db maximum throughout the facility should be used. Special consideration is necessary in the computer room. Because of the high capacity cooling system required, high volume air flows may also create noise. Sound attenuating baffles are available and should be specified in consultation with the architect. A high concentration of equipment with cooling fans will raise the noise level in the equipment rooms, though not beyond acceptable levels. Necessary peripherals with high noise levels should be provided with acoustical enclosure.

c. Lighting

A general level of approximately 75 foot- candles of diffuse fluorescent illumination is recommended throughout the facility. Care should be taken to pre-

vent glare on the CRTs from general room lighting. Special provision must be made for dimming lights in rooms with system dispatcher consoles. Local switches should be provided to extinguish the fluorescent lighting in a minimum of three stages, while still maintaining uniform illumination, or to turn lighting off completely. Each system dispatcher station should be provided with an additional 50 foot-candles of direct incandescent illumination which can be dimmed from 0 to 100% in a continuous fashion. It may prove to be more convenient if local lighting could be controlled at individual dispatcher stations.

d. Electrical Interference

Interference problems can become very complex, and must usually be evaluated in the context of specific equipment arrangement, cable runs and power distribution. Interference problems produced by the facility can usually be predicted and avoided in advance. Electrostatic discharge between personnel and equipment can cause disturbances in computer circuitry. Two precautions are helpful in solving this problem: (1) maintenance of acceptable levels of humidity, and (2) the selection of static-free materials for use in these areas. Anti-static carpeting should be used in the control center and throughout the facility. Similarly, anti-static fabrics should be specified for coverings on any furnishings in the area. Incandescent lighting is recommended where dimming is necessary. Dimming controls should be of the autotransformer type.

4. Power Conditioning

The following paragraphs discuss the power supply, distribution, redundancy, and the grounding required.

a. Power Supply

Because of the importance and uninterruptible nature of system control operations, substantial redundancy should be designed into the control equipment. A corresponding level of redundancy should be provided in the power source to assure an uninterrupted flow of conditioned power. To satisfy system reliability requirements, the power supply configuration should be comprised of two independent distribution lines, a solid-state uninterruptible power supply subsystem, and an emergency engine generator. The power supply system

should be sized to accommodate both present and future requirements.

b. Grounding

The physical characteristics of the ground network depend heavily on the arrangement and characteristics of the equipment purchased. The supplier of the control center devices may specify a ground network to be installed on the building floor. A single earth ground will be necessary for signal grounds. All signal grounds should be connected to this point, either by a radial network, or a point to point system. Equipment with ground busses in each cabinet will reduce the complexity of the grounding network. For initial purposes, it will suffice to provide a low impedance connection to earth at each of the main power distribution boxes.

F. Staffing and Training

Computer systems of the scope described herein require a full-time senior engineer completely responsible for all phases of the project. During the preparation of the specification and the evaluation of proposals this engineer, the Project Manager, will require support from several specialized technical disciplines. The project team should include, as a minimum, personnel having experience in the details of the generation and sub-transmission network, modern digital hardware, and real-time programming. After contract award, during implementation of the system and until the completion of acceptance tests, the expertise demanded of the project team shifts, requiring the addition of programmer/engineers and maintenance personnel. Portions of the project staff form the nucleus of the permanent staff.

1. Project Staffing and Personnel: In addition to normal project duties which include ensuring Vendor compliance with the specification, contract negotiation, cost control, and project scheduling, the project team will be concerned with the following tasks:

   - Coordination of project activities with participating departments and member cooperatives
   - Telecommunication hardware manufacture and tests
   - Conceptual design and implementation of the communications network
   - Console design, manufacture and test
   - Miscellaneous hardware manufacture and tests
   - RTU manufacture and tests
   - Scheduling of deliveries of equipment and application programs
   - Software development
   - Integrated hardware and hardware/software tests
   - Site preparation, consultation with architects and interior designers
   - Installation

° Field tests and availability tests

° Start up

a. Project Manager: The Project Manager is responsible for the specification and procurement of a system that will eventually control and monitor all of generation, sub-transmission equipment, and/or distribution system. The Project Manager should be a senior engineer having working knowledge of the equipment and its interrelations with the operations of the entire cooperative. Supported by specialists on the project team, this individual would also require familiarity with the characteristics and limitations of the hardware and software currently employed by Vendors to implement energy control systems. The Project Manager's commitment to the project must be full-time from the planning stage through acceptance testing. His activities should be divided equally between management responsibilities and assisting in the software efforts. Project Manager tasks will include:

° Overall coordination of project team manpower
° Monitoring Vendor performance
° Liason with the building architects
° Conducting project review meetings
° Maintaining the project schedule
° Aiding in the data base implementation

The Project Manager can be expected to be committed for the full course of the project.

b. Engineering Support: Distinct areas of expertise can be identified within the project team's engineeering staff. Each area will require a general electrical engineering background supported with specialized application experience. Tasks to be covered by the engineering staff include:

° Monitoring the Vendor"s implementation of hardware and software
° Supplying the Vendor with specific data base documentation
° Approving CRT formats
° Designing all RTU installations
° Designing the communications system

The specification, monitoring and approval of Vendor supplied hardware and software should be accomplished by an engineer with experience in the characteristics of real-time systems. The responsibilities of the Digital Systems Engineer will require a full-time commitment to the project, initiating at the time of contract award. Early in the implementation phase of the project this individual should attend the pertinent courses offered by the Vendor covering the operation of the system hardware and software. The engineer's project responsibilities will include evaluation of Vendor-supplied non-standard hardware and configurations, approving system test procedures, aiding in the data base implementation, specifying and reviewing man-machine interface operation and participation in system testing at the Vendor's facility.

Any project needs concerning detailed information about generating units, substations or other equipment should be the responsibility of a Power Systems Engineer. Additional responsibilities include the design of RTU installations, and coordination of the interfaces with other power systems. This function will require full-time commitment up to the time of system operation, and part-time involvement after this point to coordinate the system configuration.

A third engineer, working on a half-time basis will be necessary after contract award. This position, the Communications Engineer, will be responsible for the design and implementation of the communications system.

A small drafting and clerical staff is required to aid the engineering staff.

After acceptance these individuals will be responsible for directing and supervising the activities of computer programming, hardware maintenance and general system related operations at the Energy Control System.

c. Operations Support: The Manager of Operations should assign a representative to the project to ensure that the control room equipment and services are designed to provide optimum service to the System's Dispatchers and promote Dispatcher acceptance of the new system. The computer project will require this individual on

a half-time schedule to design and review formats for all man-machine interfaces including logging, trending and display requirements. These functions will be accomplished in parallel to this individual's main task of designing the operating procedures.

The individual will be required to attend Vendor training courses covering the operation of the system. This information, and the final operations documentation will be used in training the System Dispatchers.

d. Programming: One programmer/engineer and the digital system engineer should attend all appropriate courses offered by the Vendor early in the implementation phase of the project. As the software design proceeds, these individuals will provide software monitoring assistance to the Project Manager. The programmer/engineer should also be assigned tasks developing selected application programs for the control center and participate in the integrated system test of the Vendor's facility. The application programs may be written while the individual is assigned to the Vendor's plant.

e. Maintenance: The experience of utilities with control systems shows that in-house maintenance capability is superior to complete reliance on Vendor field support to achieve the high availability required. Utility personnel respond faster to isolate hardware problems and restore system operations when failures occur. Familiarity with the actual installation and continual performance monitoring allows company personnel to detect and remedy incipient hardware problems before they result in system failures. Vendors, by contrast, normally concentrate their system maintenance engineers at headquarters. Additional time and costs are spent to effect most repairs. Constant maintenance by dedicated Vendor personnel on the other hand would be far too costly. The Borrower should perform all maintenance and rely on the Vendor only for extremely difficult failures and the repair of complex system elements.

The maintenance of the master station should be the responsibility of highly motivated, well-trained personnel. The maintenance of computer equipment require skills beyond those of average technicians. Once trained, computer maintenance men are in great demand in industry, and the borrower must make this

position an attractive one for competent individuals. Two master station maintenance technicians are required to provide round-the-clock on-call support, and to assure that if one key man is not available, or seeks another position the system will not be subjected to loss of all preventive and repair maintenance. Both individuals should attend all available courses covering hardware, diagnostic software, and communication equipment offered by the Vendor during the implementation phase of the project.

In addition, on-site RTU installation and maintenance training should be conducted for the two maintenance engineers and a maximum of six individuals who will be used to maintain RTUs located at distant sites. It is recommended that a minimum of three remote maintenance sites be established, to be staffed by the six RTU maintenance technicians, and that these sites be equipped with test equipment and spare parts sufficient to accomplish normal repairs. Personnel for this function could be drawn from the maintenance staffs of the member co-ops.

Valuable additional training is available during checkout of various subsystems during system integration prior to acceptance testing. Maintenance personnel are expected to play an active role in system testing at the Vendor's facility, and in installation and acceptance testing. Maintenance personnel will report to the digital systems engineer on the Project Manager's staff.

f. Consultants: If the Borrower is unable to provide the full project staff, consideration should be given to the use of consultants to supplement the available manpower. Three reasons make this approach feasible: (1) it eases manpower requirements during the difficult early months of the project; (2) allows the timely completion of the project without costly delays resulting from lack of personnel for design and/or monitoring purposes; and (3) the consultant brings to the project an objective knowledge of the Vendors and their systems based on the wide experience of its staff which can be acquired in almost no other way.

The Borrower should consider utilizing consultants to provide expertise in these specific areas;

- Preparation of the specification, Vendor evaluation, and negotiation
- Planning, specifying and implementing the communications network
- Monitoring the Vendor's progress in software
- Project overview - utilizing consultant's experience on similar projects to monitor Vendor performance

Consultants should be considered a temporary expedient, however, and in no way a substitute for direct Borrower involvement in the design and implementation of the system, or the Borrower's proficiency in all aspects of the system's daily operation. The lesson learned expensively by many utilities is that a computer system is as successful as their staff's daily and in-depth technical involvement in it. The computer system cannot be considered equipment which, after careful specification and purchase, performs, unattended, until it is replaced.

2. Permanent System Staffing: Acceptance of the new system implies the existence of trained personnel to operate, maintain and update it. The basic staff should consist of personnel previously assigned to the specification and implementation of the project. Additional manpower will be trained subsequently and given hands-on- experience with the system. After system acceptance, the control system staff should consist of one digital system engineer, one programmer/engineer, two master station maintenance men, and six RTU maintenance men located in the field. The ongoing requirements for engineers and programmers is a direct function of the development work the Borrower may elect to accomplish in-house. The initial personnel assigned to the permanent staff should participate in the factory acceptance test.

   After system acceptance, programming personnel involved in the monitoring and implementation of the new system will continue to perform daily updating and longer-range software development tasks. Sufficient development work should remain to ensure the continued interest of programming personnel, and minimize diversions. These programmers will report to the Digital System Engineer.

3. Training: The training of borrower personnel should be geared to achieve the following objectives: ensuring the system's availability to System Dispatchers by quickly isolating and correcting failures; ensuring that backup devices are always ready to assume on-line functions; permitting expansion and reconfiguration of hardware and software to match the changing electrical system; and promoting a thorough understanding of the capabilities of the computer system with its assigned staff.

Whenever possible, training courses should be conducted at convenient on-site locations. Other locations are acceptable if the technical material can best be covered there, or the number of participants is small. Training should be conducted by experienced personnel, supported by modern training aids. Individual copies of technical manuals and pertinent documentation should also be given to participants at the time the course is conducted. The courses should be scheduled in a staggered manner so that one man could participate in all of them.

Training courses and most participation by the Borrower during the system implementation will be at the Vendor's facilities. Detailed schedules of activities cannot be predicted. Borrower engineers, maintenance personnel and programmers, with the exception of operations personnel, must be dedicated to the project and should not be assigned to other duties until the system is successfully installed.

a. Hardware Maintenance Courses: Engineering and maintenance personnel should attend two courses dealing with the hardware furnished with the system. The courses should occur within three months of the integrated factory acceptance test. One course should deal with the computer mainframe, its operation and capability as a diagnostic tool. The second course should cover the peripherals, their interface with the mainframe and the operation of their internal logic, remote terminal units and telemetering equipment. These courses should be structured to enable maintenance personnel to operate actual equipment, run off-line and on-line diagnostics and repair failures. Additional training courses provided by subcontractors should be attended if they are available. This is of particular importance for the CRT and printer hardware. The latter courses should be more detailed and cover all aspects of electronic and mechanical operation.

b. <u>Software Courses:</u> The Vendor should provide extensive software training for the project staff. Software courses should aim at familiarizing the staff with all aspects of the systems programming characteristics. These courses should begin as soon as possible after award of contract. Software courses should be presented in three sections:

(1) A course covering the assembly languages, I/O interfaces, debugging tools, and the operating system, from the point of view of the programmers using the equipment and software.

(2) A course covering any high-level programming languages as required for the computers, and their interface with the operating system.

(3) A course offering a detailed study of the specialized software supplied by the Vendor and the detailed logical structure of all standard software used by the system.

The courses should foster familiarity with off-line and on-line procedures for the generation of programs, operation of peripherals, use of documentation, use of the computer console, start up and shut down procedures, and the use of off-line and on-line debugging aids.

c. <u>System Dispatcher Training:</u> The System Dispatcher training course should be divided into three segments to increase involvement and understanding of the system and keep instructional periods to a minimum: Familiarization, start-up training and subsequent training. The familiarization would be a short course held at the facility thirty to sixty days before the system is shipped. Manuals should be distributed prior to this class. This course will introduce system concepts and general design features to the System Dispatchers. The project staff would be the best equipped to conduct this and subsequent System Dispatcher training courses.

During installation and start up, the second section of the course should be given. This course will include hands-on operation of all equipment, and practice in the procedures required to perform various tasks. To increase the usefulness of the system during

this period, a special training mode will be provided. This training mode would allow access to any CRT display and CRT changes to a substation or functional display, without transmitting commands or otherwise distributing the RTUs.

After the system has been accepted and is in operation, a continuing training program will be initiated. New System Dispatchers will be trained using the Programmer/Engineer/Training Console. In the training mode, the system will provide all console functions, except control actions, which affect the power system. As new functions are added to the system, the System Dispatchers will be trained in their use without jeopardizing the security of operation.

The courses should be conducted by the operations representative assigned to the project staff. This individual will require training from the Vendor in the initial phases of the project, sufficient to allow preparation of the course material to be presented in the dispatcher training.

G. Documentation

While the Vendor is responsible for the system operation and maintenance through the final acceptance demonstration, it should be the practice during the latter phases of the project for the Vendor to use Borrower operations personnel to the maximum extent possible for on-the-job training.

It should be the goal of the Borrower to become self-sufficient in all aspects of maintenance as soon as possible. Until that time, it may become necessary to contract appropriate levels of follow-on support maintenance. In order to a assure that the Borrower has the opportunity to become self-sufficient in a timely and orderly manner, it is necessary that the Supplier provide quality documentation and quality training. Adequate program management should be provided, to assure that Borrower personnel receive the product and services required. In this regard, documentation should be provided which describes the system and interfaces in support of testing, installation, system activation, operation, and maintenance. The requirements for documentation are discussed in the following sections.

1. System Design Specification

The Supplier should develop, during the program initial design phase, a detail design specification which will become the baseline for the hardware and software systems configuration and performance to be delivered in the course of the contract. The design specification document should contain as a minimum:

- Description and configuration of the system and identification of deliverable hardware and software subsystems

- Description of deliverable documentation

- System performance of both hardware and software subsystems

- Overall test and performance demonstration plan, including the level of tests to be performed to assure the system meets the stated performance values

- Detailed description of system interfaces

2. Hardware Documentation

A hardware documentation package should be established to include:

- Block diagrams showing the overall system and information data flow
- Hardware layout and assembly drawings showing equipment arrangement, configuration, dimensions of each rack cabinet, console, display panel, module, etc.
- Internal wiring diagrams and listings
- Schematic or logic diagrams of all modules, panel assemblies, etc.
- Schematics for use in defining system operational modes and functions
- Interface connection and control drawings, and wire point listings between system and telephone, and power company equipment
- Site preparation, installation drawings and procedures. Includes: power, grounding, and environmental requirements, cable routing, safety precautions and equipment handling, procedures for mechanical assembly of consoles and racks, list of installation tools to install each piece of equipment. etc.

3. Software Documentation

A software documentation package should be established to include:

- Program requirement specifications
- Acceptance test procedures and test reports
- Program description documents
- Program interface control documents
- Configuration control methodology
- Annotated program listing documents

- Maitenance and users manuals
- Source card decks
- Object card decks, tapes, or disk

The program requirements documents should define "what" is to be programmed. The description documents define"how" each requirement is mechanized or implemented. Documentation detail should be sufficient such that a semi-experienced assembly language programmer can readily make modifications to the system.

Software should be of modular construction, with provisions made for updating a module without reassembling the entire program. Linkage conventions must also be standardized and well documented. A program listing with comments does not in itself constitute a documented program.

A Software Acceptance Test Procedure defines what constitutes acceptable software performance, and how each software package is to be tested, to assure proper operation and conformance to specification requirements. The test reports document the results of each test performed. The software descriptions should include main frame related software.

A users manual should be provided that contains as a minimum:

- Description of the overall software organization
- Narrative description of each program
- Instruction language, data format, and coding
- Program explanatory material such as macro and micro flow charts, logic, and cross-referencing
- File input and output requirements
- Storage maps
- Interfaces to other programs
- Hardware requirements
- Supporting program requirements
- Program constraints

- System features and related materials

- Variable cross-reference tables

4. <u>System Operation and Maintenance Manuals</u>

The manuals supplied should provide instructions for the system operation, preventive maintenance, troubleshooting, and repair. Manuals should also cover the following subject areas:

- Computer subsystem operation and maintenance

- Data acquisition and subsystem operation, and maintenance

- Man/machine subsystem operation and maintenance

- Software control subsystem programming manuals and maintenance

- System operator procedures

- Standard equipment

The manuals should contain the following general topical structure:

- <u>System Concept, Function, and Interface</u>

  General description of system
  System function and modes
  System interfaces
  System theory of operation
  Supplemental system data and drawings

- <u>Subsystem Concept, Function, and Interface</u>

  General description of subsystem
  Subsystem function and modes
  Subsystem interfaces
  Subsystem installation details
  Subsystem theory of operation
  Subsystem maintenance procedures (as applicable)
  Subsystem equipment configuration
  Equipment manuals
  Repair parts identification
  Test equipment requirements
  Supplemental subsystem data and drawings

5. Training Documentation

A training program should be obtained from the Vendor detailing individual training courses as follows:

- Duration
- Location
- Qualification of instructors
- Objectives
- Prerequisites
- Content
- Outline
- Training materials (handouts)
- Audio-Visual aids
- Special equipment, tools, etc.
- Ratio of classroom to hands-on laboratory experience

The basic courses to be considered in the training plan are:

- Power System Operation - The instructions on how to use the consoles, CRT, and other man/machine equipment in the control room
- Computer System Operation - The instructions on how to operate the computer system, system failover, restart the system, and operation of peripherals
- Computer and Peripheral Maintenance - The instructions on how to maintain, troubleshoot, repair, and adjust the equipment supplied by the mainframe subcontract or
- System Hardware Maintenance - The instructions on how to maintain, troubleshoot, repair, and adjust the remainder of the hardware supplied at the system operations center, including such items as the CRT monitors, display drivers, printers, console devices, interface logic backup devices, communications equipment, video hard copies, etc.

- RTU Maintenance - The instructions on how to maintain, troubleshoot, repair (at a module/card level) and adjust the remote equipment using their associated test sets

- CPU Software - The instructions on how to efficiently use and program the mainframe supplied software, utilized and supplied with the system, including the real-time operating system, assembly languages, programming, instruction set, loaders, assemblers, compilers, macro language and usage, higher order languages, machine functions, and control machine services, system build, program debugging, etc.

- System Software - The instructions on how to efficiently use and maintain the system software supplied as part of the system by the Vendor, including communications software, report generation, display generation, data base and display generation and change, failure detection software, etc.

- Application Program Software - The instructions on how to efficiently use and maintain the applications programs supplied as part of the system by the Supplier

6. Maintenance Plan and Spare Parts

The Vendor should submit a maintenance plan and list for spare provisioning. The plan should develop the philosophy, and detail the procedure for transfer of maintenance responsibility from the Vendor to the Borrower. This should be coordinated with the training plan. It is the desire, that within a reasonable period of time, the Borrower become self-sufficient in all aspects of maintenance.

The initial spare parts list should show type and quantity of all spares expected for use in the system, and the expected attrition rate of each part, module, etc., supplied, to support normal operation over a one-year period.

7. Program Documentation

As a standard procedure, schedule updating and status reports describing activities, accomplishments, and problems should be submitted monthly, until the system is finally accepted.

Plans should be developed for the following efforts:

- Training
- Maintenance
- Test and acceptance
- System program management

8. Project Coordination and Management

A program management plan detailing how the project is to be scheduled, coordinated, and managed should be developed. The plan should, as a minimum, cover the following project phases:

- System design
- Quality assurance
- Procurement
- Software development
- Subsystem hardware/software test
- Factory system build and acceptance test
- Installation
- Integration and activation
- System demonstration, on-line evaluation, and final acceptance
- Program status and reporting

The plan should detail the available personnel resources and management by name, including the project manager, and his specific responsibilities. Qualifications of key individuals should be included, along with their present assignment to this project.

The plan should detail how a realistic schedule is to be developed and managed; how work is to be defined, scheduled, and controlled; how software design, coding, integration, and test are to be controlled; how design reviews are to be accomplished, how changes are controlled,

how contract data items are scheduled, produced and delivered; how subcontractors and suppliers are to be managed; how quality assurance is to be enforced; and how liaison and reporting with the Borrower is to be accomplished.

9. Document Changes

Documents should be identified by a document number. Changes and revisions should be appropriately indicated on the face of the drawing by a change sheet in the front of the document. The information on the drawing or change sheet identifies the change number, date, and subject of change, location of change, requesting and/or approving document, and authorizing person. Actual revisions to drawings or document pages may be marked or otherwise identified for ease of location.

The Vendor must be responsible for maintaining change control over the delivered document set for a period which extends through the warranty time. This includes all corrections due to hardware changes, and document inaccuracies or deficiencies determined during usage. Changes to published documents should be made by substitution of corrected pages or drawings for the incorrect pages or drawings. Changed pages should be suitably marked for a date of change, and areas on the page that were changed.

H. General Design Criteria

This section describes goals which may be used as system design criteria. The system should meet all objectives, consistent with some degree of compromise to optimize cost. Currently existing circumstances, operating philosophy and the growth characteristics at most Borrower facilities should form the requirements and guide engineering decisions.

1. High Availability

Considering the importance of supervisory, dispatching, and control activities in terms of the value of daily production, loss of control, in whole or in part, cannot be tolerated for more than extremely short periods. Typical systems can be expected to achieve the industry standard of 99.8% availability for critical functions. Higher availability may not be possible to achieve except at an unreasonable expense. The figure of 99.8% is, however, unrealistically high for single computer configurations. A 99.8% availability will result in a cumulative failure rate of 17.6 hours per year, well within the capabilities of currently available dual computer systems. Lesser availability figures would be acceptable for equipment elements other than those directly concerned with control and data acquisition functions.

2. Redundancy and Backup Goals

The proposed ECS or SCADA system should be designed so that a single component failure anywhere in the system will not result in the loss of a critical function. Where feasible, multiple component failures should be protected against, particularly where devices are more susceptible to outages and/or have potentially long repair times. If a spare component is required to maintain high system availability, and it can be useful in supporting a noncritical function, it should be incorporated as an on-line component. Of all functions, data acquisition, supervisory control, and automatic generation control, are considered of prime importance. Other critical ECS functions should be defined as system design proceeds.

3. Reliability and Security

The proposed computer system should have strong reliability and security characteristics. Reliability is defined as the readiness of the system to operate whenever

circumstances and a dispatcher require it to operate. Security is defined as a characteristic which prevents the system from operating except at the expressed and verified demand of a dispatcher or the built-in logical functions of its programs. Both characteristics must be incorporated into the hardware and software of the system during design, specification,and implementation.

4. State-of-the-Art Design

Although it may be possible to procure a reliable system which satisfies current system functions in a traditional manner, the proposed system should utilize, wherever practicable, proven state-of-the-art techniques. These techniques are usually developed to solve shortcomings in existing systems, or to satisfy expanded needs not adequately satisfied by existing equipment. Many of these techniques are involved in man/machine interfaces. Others improve the reliability and security of the hardware of computer-based systems. State-of-the-art approaches to system design should not incorporate difficult maintenance problems. State-of-the-art approaches should not involve developmental work on unproven control techniques, or the purchase of an experimental system. Rather, they should improve monitoring and control capabilities of the system and forestall premature obsolescence.

5. Man/Machine Interface

The new control system is primarily a dispatcher tool. New techniques which improve the efficiency, ease, and speed by which equipment may be monitored, dangerous conditions pinpointed, control actions forwarded to remote equipment, and monotonous activity relieved, must be seriously considered. The dispatcher must be given tools which allow him to perform his increasingly critical tasks satisfactorily.

6. Conservation of Manpower

Operational use of manpower is a direct function of system design. The new system should require a minimum number of personnel for daily operations, updating, and maintenance. In evaluating system concepts, the effective use of dispatcher manpower is of prime importance.

7. Minimum Capital Investment

In any uncertain State-of-Money market, the goal of minimum capital investment is of great importance. This goal must be considered an important, but not the only element of the total cost of the system over its useful life. Low initial capital cost may, for example, be negated by high operating costs, maintenance costs, and the costs for expansion beyond the portion of the system initially purchased. The main cost of a large control system lies in the cost of its software and remote terminal units, and their installation and servicing, rather than the cost of the master equipment.

8. Economic Operating Costs

This goal must be coupled with minimum manpower, maintenance, communication, and capital costs. The control system should be easy to maintain and have a minimum incremental relationship between RTUs and added operating maintenance personnel. It must be accepted, however, that every added piece of equipment will increase operating costs in the form of communication requirements, maintenance, and amortization/depreciation expenses, even though direct manpower costs may not be affected.

9. Economic Communication Costs

While the tradeoffs between manpower and communication is generally in favor of the latter, there is still ample opportunity to design a system which minimizes communication demands. These costs are particularly heavy if multiple separate communication paths serve the same location for purposes of back-up or redundancy. Party lining of selected RTUs, without loss of effective control practices, is an acceptable operation, since considerable savings in operation can be a result.

10. Maintainability

The control system should be designed for ease of maintenance, using a minimum number of personnel. Shelf spares for vulnerable items of equipment should be held at a central location. Stockpiling of expensive major items of equipment should be avoided, and are not necessary to attain acceptable standards of availability. Training of personnel should not be wholly dependent on the equipment manufacturers, nor should the education level and training demanded of maintenance personnel be

excessively high. Equipment should be easily accessed,not sensitive to normal ambient temperature changes, and not dependent on an uninterrupted air conditioned environment for proper operation. Diagnostics for all system elements should be supplied by the manufacturer and available to organizational maintenance personnel.

11. Expandability

Hardware and software should be capable of easy expansion, with minimum downtime, to accomodate anticipated growth in any system. During the life span of the system, the number of lines may be increased, new generating units added, and the software asked to perform sophisticated analytical tasks. The system must be expected to grow with increases in the size or number of auxiliary memories, and the addition of main memory modules and I/O channels. Additional peripherals for logging, plotting, display, or data collection, may be added during the life of the system. The selected system should be capable of absorbing normal computer system growth. Capability for expansion should be purchased, though it may not be fully activated for a number of years to come. Expansion capabilities must be included in the specification to prevent costly under, or over-design by a manufacturer.

12. Life Span

The new system should have a minimum life span of 12 years. Based on the experience of other utilities, 12 years is a reasonable goal. In earlier systems where initial functions were firm, functional additions minimal, and the electrical system relatively static, life spans longer than 12 years were achieved. Normally, digital systems will deteriorate with age, particularly all electro-mechanical peripherals. Availability will decrease with time, and replacement or compatible equipment will become difficult to obtain. The system design should allow for the possibility of expansion to include all anticipated future functions. RTUs can be expected to have a life span well in excess of 12 years. Master station life span will depend on the existence of spare parts, the quality of maintenance performed, and the commitment of manufacturers to continue support for their older products.

Technological obsolescence will also have influence on the effective life span of a system. The continuous progress of the computer industry towards more powerful and less costly equipment has allowed manufacturers to offer new applications for systems in each evolutionary cycle. As the control system passes through mid-life, newer systems with added and improved functions will add to the forces propelling the system towards end-of-life. A continuous evaluation must be performed at this stage of system life, balancing the worth of continued use and maintenance of the current system against the cost of replacement.

13. Personnel Safety Design

Control systems design should incorporate the following system features:

- All operating controls should be kept at ground potential.
- Wherever operating voltages in the equipment exceed 100 volts, the equipment should be shielded from accidental contact and should be protected accordingly.
- Equipment should have no sharp corners or edges. All edges shall be rounded to prevent injury and accident.
- Equipment should be designed in accordance with the Underwriters Laboratory specifications for fire resistance, and in accordance with state and local safety codes.

IV. SYSTEM IMPLEMENTATION

A. General

This section reviews implementation plans from the problem definition phase through operational checkout. The implementation passes through three broad phases:

- Information gathering - begins with a problem in system control and ends with alternative solutions
- Learning - starts with selecting one of the alternatives and ends with the installation of the control system
- Execution - this final phase starts with the date the system is turned over for operation, and ends when management decides to replace the system

An energy control center design passes through at least seven distinct phases in its implementation process. The phases are:

- Problem definition
- Preparation of functional specifications
- Evaluation of Bids and Project Schedule
- Design approval and Responsibilities
- Acceptance testing
- Installation
- Operational checkout

Each phase requires close coordination between management and engineering in order to effect system implementation liaison with the Vendor during the design, test, installation, and operational checkout of the system.

Once it is decided that a problem exists, and prior to the start of the definition phase, it is necessary to establish a team for investigating and assessing the potential of implementing a control system. This begins with the selection of a project manager. The project manager should be from the user organization, preferably from the operations group.

The composition of the study team depends upon the resources of the electric system Borrower. Ideally, the study team should be comprised of an individual from each of the follow-

ing organizations, as applicable to the particular Borrower structure (i.e. Generation and Transmission or Distribution System Borrower):

- System operations
- Transmission engineering
- Distribution engineering
- Dispatch
- Test department

B. Problem Definition

Most Borrowers control centers are an evolution of some form of manual or semi-automatic dispatch operation, put together by operating personnel responding to the day-to-day operations and crises of their jobs. In many instances, it is neither possible nor prudent, to launch into a study without either consulting, or learning how the dispatcher functions. Furthermore, it is unwise to procure a system which is less than optimal in either assisting the dispatcher, or in augmenting the dispatch function. By the same token, no system design is totally predicated on the desires of the dispatcher. Rather, this most important phase is approached with a set of objectives which are consistent with the mission of the Borrower, that is, as he may function as a G&T or a distribution facility.

The procedures of the problem definition phase as simply stated are:

- Review present operating methods and systems
- Develop basic functions to be performed by the system
- Develop several alternative solutions and:

    make technical and operational comparisons
    make economic comparisons
    select a preferred concept

- Establish detailed functional requirements for a preferred concept
- Establish building and related facility and support requirements
- Establish a project implementation plan

Borrowers are finding that the use of outside engineering services to assist in performing requirements studies has several significant benefits. The consultant will have performed similar studies for other utilities, and will be very familiar with current state-of-the-art practices, in defining new control system requirements. He will apply this experience to the project and can substantially improve the prospects of achieving the planning objectives. It is expected that the cost of such services will be offset by savings in the overall system life-cycle costs.

Once the problem has been identified, with the possible increased costs of operation due to existing methods known, management will need to know the magnitude of resources required, and the potential benefits and risks involved if the project does not go as planned.

C. Preparation of Functional Specification and Contract Document

The specification for the control system, while presenting firm functional requirements, should be as nonrestrictive as possible in describing actual implementation. Utilization of a Vendor's standard existing hardware and software, where this hardware and software satisfies functional requirements, is clearly to the Borrower's advantage. Where designs are presented to the Vendor, they should be presented as suggestive of intent rather than absolute requirements.

The specification for the control system should be written with the difficult task of evaluation in mind. Simple timing studies, algorithms, and test cases should be provided. A questionnaire embodying important specific questions concerning the characteristics of the proposed system will aid the project staff in evaluating proposals, and provide an index to the voluminous material normally associated with proposals of this type.

Many companies are presently producing SCADA/EMS Systems and are potential suppliers of the control system. Careful preselection of Bidders is necessary to optimize the quality and effort of the proposal evaluation by the project team. Experience and capabilities vary among Vendors and individual evaluations are required to establish acceptable candidates. A Vendor's experience with projects of comparable scope and complexity will impact the implementation period, possibly extending the time from contract award to final system acceptance. The supplier's initial capability plus his interest and ability in servicing the project throughout its useful life are considered of primary importance.

The project team assigned the task of evaluation of the control system offerings should embody their findings in a formal evaluation report. This report will summarize, for their own and management's use, a comparison of the systems offered by the Vendors. The pricing instructions of the specification will aid in the preparation of a tabulation displaying the cost of individual elements of the system. Reasonable costs will also be assigned to such imponderables as future service risk, man/machine convenience, programming ease, experience of the Vendor in electric utility applications, developmental risks and others. The evaluation report will be based on a close reading of the proposals, formal presentations by the Vendors, the Vendors' replies to questionnaires, and, in some cases, direct visits to plants and existing installations where the equipment proposed is in daily use.

Following an authorization to proceed, the successful Vendor should be prepared to participate in a joint effort with the project staff to produce final contract documentation based on the specification. This document will consist of the specification as modified by a table of conformance. This table of conformance shall address each paragraph of the specification and shall state the extent to which the delivered system will deviate from the specified requirements. The Vendor's proposed implementation and technical agreements reached during prebid and evaluation phases shall thereby become a part of the technical contract. The document should be used as a guide throughout the project, and be binding on both parties.

D. Evaluation of Bids and Project Schedule

1. Bid Evaluation

The bid evaluation is one of the most important, if not the most difficult, phase of a project. It requires not only the skills of both hardware and software engineers, but also the ability to assimilate and integrate all facets of the Vendor's proposal. If the Borrower's engineering has participated to the fullest extent up to this point, much of the burden may be offset. However, this is a point in the project where the services of a qualified consulting firm should be considered.

The following are some considerations and methods that may be used for bid evaluation:

- Rank the items of the system functional specification as MUSTS or WANTS and determine how each proposal satisfies both categories

- Purchase an operating system supplied by the Computer manufacturer

- Establish past performance of the Vendor on Energy Control Center projects

- Determine the number of years a Vendor is capable of supporting his product

- Request an itemized quotation for elements of hardware and software -- this is particularly important if you are going to normalize various proposals to a standard offering.

- Determine the limitations of the proposed system provisions for future hardware expansions

- Evaluate what trade-offs can be realized between memory requirements and higher level language for system programming

- Determine if your consultant's assistance in evaluation expertise is competent in all the required areas

A detailed report of the bid evaluation, with recommendations, should be prepared for both Borrower management and REA review. The emphasis should be on how the selected proposal best meets the objectives of the planned control center design, and why the other alternatives do not.

2. Project Schedule

A typical Project Schedule for the design, implementation, and testing of the ECS is discussed in this section. The estimates used in this schedule are based on average task times for illustrative purposes only, and serve to identify, chronologically, the sequence of events in the overall project implementation.

Phase Schedules

The estimates contained in this section are presented in terms of average calendar weeks to complete. Phases are well defined groups of tasks, bound by time, culminating in milestone documents.

- Phase 1 - This phase commences with the submission of a report which includes time for the review of the report, design of an acceptable system and

its specification, and the review of the specification. Approximately 26 calendar weeks have been allocated for this phase

- Phase 2 - Allow 8 weeks for bid preparation by the Vendors. During this period, the project staff will continue expanding system design requirements, and gathering the detailed system data that will be required by the successful bidder. During Phase 2, proposals will be carefully evaluated and the findings and recommendations of the project staff summarized in a final evaluation report. Following delivery of a letter of intent to the selected Vendor, a final contract document will be signed based on the specification, the Vendor's proposal and any agreements reached during the evaluation and presentation period. A total of 25 calendar weeks are allocated to Phase 2

- Phase 3 - Encompasses all activities between the time the contract is signed and the time the system is shipped from the Vendor's manufacturing facility. The activities are those normally associated with the production of a control system including computer procurement, hardware manufacture and test, software design code test, system integration, and the factory acceptance test. This phase is estimated to require 73 calendar weeks

- Phase 4 - Activities are performed at the Borrower's facilities. During the ending weeks of Phase 3, the control room and equipment rooms have been prepared to receive the consoles and equipment. Installation (4 weeks) is followed by start up and check out (4 weeks), and a preliminary field acceptance test similar to the factory test. Final acceptance of the system follows successful running of a 1000 hour availability test. The test can be expected to require 12 weeks to complete

- Phase 5 - Identifies, and chronologically orients the activities that must be accomplished to ensure the availability of the ECS building and communication facilities when the computer system is received

The time required to achieve full system operation is approximately 133 weeks. A 1000 hour acceptance test will require an additional 12 weeks.

E. Design Approval and Responsibilities

1. Design Review and Approval

Preliminary final design reviews approvals should be held by the Supplier at his facility to conserve costs. The Borrower should be prepared to provide acceptance approval at each of these reviews. The preliminary design review should be held early in the program, before any major design effort has started and later in the program before any major fabrication or coding has started. These design reviews are used to assure that maximum compliance to the functional requirements is being accomplished.

2. Vendor and Borrower Responsibilities

The Vendor and Borrower both share in the responsibility of designing, fabricating, integrating, testing, and demonstrating the hardware and software comprising the ECS. Vendor and Borrower responsibilities are defined in the following.

a. System Design, Fabrication, Tests, and Delivery

It is the Vendor's responsibility to provide for the system's hardware and software design, manufacturing, preparation, assembly integration, and test. The Vendor shall be responsible for functional integrity of all the internal and external system interfaces. Where required the Vendor shall make on-site visits to determine interface requirements.

The Borrower should provide all necessary updated power system information.

The Vendor should be fully responsible for the packing and safe shipment of all system hardware.

b. Documentation

The Vendor shall provide all documentation in a timely and orderly manner. It will be the responsibility of the Borrower to conduct appropriate reviews of documents requiring acceptance approvals.

c. Training

The Vendor should describe a training plan as part of this proposal and furnish all training courses unique to his equipment. The Borrower should coordinate with

the Vendor in making personnel available to attend these courses.

d. Quality Assurance

The Vendor is to provide a complete description of his Quality Assurance Plan, and he shall be responsible for conduction Quality Assurance Inspections, tests, and reporting in accordance with his Quality Assurance Plan.

e. System Activation

The Vendor should furnish a system activation plan and procedure. The Borrower and Vendor must work together in the accomplishment of a secure and smooth system activation and cutover.

f. Performance Warranty

The Vendor should provide at least a one (1) year performance warranty on the total ECS beginning at the time of final acceptance. The warranty should cover the repair, rework, replacement of any hardware or software items that do not meet the performance and availability requirements of the specification. This warranty should cover all parts, materials, labor, travel, and perdiem, in effecting any and all corrective actions by the Vendor.

g. Program Management

The Vendor should provide a staff of qualified personnel to manage the ECS project. The Vendor's management team should manage, control and coordinate the development of the system, integration, testing, delivery, and system demonstration and final acceptance. The Vendor should assign a Project Manager, acceptable to the Borrower, to serve as a focal point for overall project management. In like manner, the Borrower should assign an ECS Project Manager. All formal communications between Borrower and Vendor should be exchanged through the Project Managers or their designated alternates.

The Vendor should provide an organization chart showing the organizational responsibilities and names of key personnel intended to be assigned to the program. Resumes of key personnel should be provided.

F. Acceptance and Testing

All materials and hardware to be furnished and all work to be performed under the ECS specification should be subject to inspection and tests. All shipments should be deferred until inspections and tests have been completed and the Borrower issues authorization for shipment. Acceptance of hardware, or the waiving of inspection and tests, should not relieve the Vendor of the responsibility for furnishing a system that meets the specification. The Borrower should reserve the right to request additional tests on any work determined to be not in accordance with the specification. Deletions and changes to the specification during implementation phases of the project should be properly documented and approved.

1. Inspection

The Borrower's representatives should have free entry into the shops of the Vendor while fabrication and testing is in progress, or into any mill, shop or factory where the hardware or software is being produced. The Vendor should allow the Borrower's representatives, free of cost, all reasonable facilities necessary to establish that material fabrication is in accordance with the specifications. Inspection results should not relieve the Vendor's responsibility of building a system which conforms to the specification, nor invalidate any Borrower claim resulting from defective or unsatisfactory material and hardware. Inspection visits by the Borrower's representatives should be performed on a regular basis to ascertain the accuracy of submitted reports and schedules.

2. Test Plans

The Vendor should submit test plans for all factory and field acceptance tests. Test plans should be submitted to, and approved by, the Borrower prior to the commencement of each test. Hardware test plans should explain the purpose of the tests, define test inputs, specify test procedures, and define outputs to be achieved. Software test plans should include a summary of the methods, a list of test cases, and expected results. The Borrower should be given at least three weeks after receipt of test plans for their approval process. All test plans should include periods for unspecified exercising of the hardware and software by the Borrower's representatives. Factory tests and availability tests should not proceed without the prior delivery of hardware and software documentation.

3. Test Reports

The Vendor should transmit, to the Borrower's representative all factory and field acceptance tests. Each report should include the purpose and method of the tests, the persons witnessing the test, and a description of any deviations from the procedures described in the previously approved test plan. Each report should include test data that is compared with expected results. The data furnished should demonstrate conclusively that the element performed within specification during all of the tests. The observations of the Borrower's representatives present at factory and/or field acceptance tests should be included in the test report.

4. Unit Design Performance Tests

Each major unit or subsystem should be tested when fabrication and/or integration has been completed. All tests should be identified in the system schedule at the outset of the project. The Vendor should verify the schedule of individual tests in sufficient time for the Borrower to schedule manpower and finalize travel plans. In instances of insufficient notice or change of schedule beyond the control of the Borrower, the right should be reserved to reschedule test demonstrations and, if warranted, to consolidate tests.

5. Routine Quality Control Tests

All components and assemblies comprising a subsystem should be given routine factory tests. These tests should be documented in accordance with practives delineated in the Vendor's quality control and assurance programs described in his proposal. The Borrower should have access to these reports on request. No test plans are required for routine factory tests. All purchased or manufactured components should be quality inspected and tested subject to the Borrower's approval.

6. Factory Performance Tests

The Borrower's project team should witness a fully integrated factory test at the Vendor's factory. The purpose of this test is to exercise system hardware and software under simulated conditions prior to shipment. If tests are unsatisfactory, shipment authorization should be withheld and factory tests rerun. Corrective measures should be expeditiously completed when equipment and technical personnel are available. Only extra-

ordinary circumstances warrant shipment authorization prior to full compliance with the test objectives. The Vendor should be required to complete corrections at no cost to the Borrower before shipment. The successful completion of factory tests will not constitute final accemtance of the system or any portion thereof.

7. Preliminary Field Acceptance Test

Following installation of the sytem, all hardware should be aligned and adjusted, and all test readings recorded in accordance with the Vendor's recommended alignment and test procedure. The Vendor should include in his test reports a list of all hardware or components replaced or interchanged after completion of the factory tests, and prior to the commencement of the preliminary field acceptance test. After initial alignment and adjustment of the hardware, the Vendor should repeat a brief form of the unit design performance tests which were conducted at the factory. A performance test should also be conducted to verivy that correct data interchange is secured over all interfaces and that the hardware and software is fully operational.

After these interfaces are verified, the factory performance tests should be repeated at the final system locations. Allowances should be made for the absence of simulation or test gear not available outside the Vendor's factory (e.g., equipment required to demonstrate satisfaction of ambient temperature requirements). All hardware and software will be demonstrated to be operational during the preliminary field acceptance test. The exact procedures, commencement time and date of the preliminary field acceptance test will be described in advance and by mutual agreement between the Borrower and the Vendor.

8. 1000-Hour Availability Test

After the preliminary field acceptance test has proven the system to be fully operational with a full complement of RTUs, a 1000-hour availability test should be conducted, commencing at a mutually agreed time. This should be considered the final acceptance test of the system. The Vendor should be expected to have his representative on call at any time during the 1000-hour test. The Borrower's dispatcher and maintenance personnel should be expected to participate in the availability tests.

Availability should be defined in functional terms. The

system should be considered fully available if it is capable of performing all Vendor supplied functions. Loss of peripherals will not normally count in the accumulation of downtime if the loss does not interfere with the essential operation of system functions. The malfunctioning of one CRT, for example, will not result in downtime if a second CRT is operating correctly, and is available for all system functions. The loss of electromechanical devices will not result in downtime if the information normally supplied via the devices is available via alternate devices.

Downtime is measured from the time of detection to the time service is restored. Downtime clearly beyond the Vendor's control should not be counted. Power failures and outages caused by temperature changes beyond those guaranteed by the Vendor should not result in the accumulation of downtime. Diagnosis and repair may be by the Borrower's or Vendor's personnel. Should the downtime exceed the maximum allowance specified during the test, the test should be restarted after the Vendor has been given adequate time to effect changes and/or repairs. The Vendor may elect to restart the availability test at any time.

G. Installation

The Vendor should furnish plans and procedures necessary to accomplish a smooth and orderly installation and integration. The dates of these submissions shall be compatible with the overall system implementation schedules. The Borrower should furnish all architectural drawings required by the Vendor to develop the plans and procedures. The Borrower should review and approve all plans and procedures prior to performing any installation.

1. Site Preparation

The Borrower should prepare all sites for installation of equipment in accordance with the Vendor furnished installation drawings.

2. Master Station Equipment

The Borrower should perform physical placement of all equipment as specified, under the technical guidance of the Vendor.

3. Remote Equipment

The Borrower should install all RTU equipment in accordance with procedures and drawings provided by the Vendor. The Borrower will perform operational checkout of each RTU with the RTU test set. The Vendor should provide field assistance as required during the installation.

4. Transducers

The Borrower should provide and install all power system transducers.

5. Power, Lighting, and Air Conditioning

The Borrower may wish to provide the UPS and engine generator set. The Borrower should provide for building distribution and circuit protection of the critical power service. The Vendor should provide the requirements for the number of circuits and required rating of circuit breakers. The Vendor should provide general approval and general concurrence on the Borrower's UPS selection and sizing. The Borrower should provide service to the equipment cabinets.

The Borrower provides for general service, non-critical power, lighting, and room and equipment air conditioning.

6. Digital Communication

The Borrower provides all communications circuits to terminated line terminal blocks mounted in a distributing frame. Communications circuit protection should be provided by the Borrower. The Borrower should also make connections from the digital equipment to the telephone circuit terminal blocks and to the communications connections for the RTUs.

7. Voice Communications

The Borrower supplies all voice communications equipment and circuits. The Vendor should make provisions in or on the consoles to accept the switch panels and speakers. The Borrower should install all voice communications equipment.

H. Operational Checkout

As soon as the energy control center is placed into service, a 90 day moratorium should be declared on any new software

development. Both Borrower and Vendor engineering staffs should be available to answer any questions and to respond to any problems encountered by the system operator and/or dispatcher. For control an indexing system should be used on all requests showing the current status and/or completion of each item awaiting final acceptance by the operators. No changes to the system should be made until at least 90 days of operating experience have been logged on the program. All subsequent changes or modifications should be coordinated with the Vendor prior to their implementation, to ascertain the effect on the overall system design, operation, and integrity.

I. Elements of a Control Study

At some point, the need to change, or internal dissatisfaction with existing operating methods and systems, will lead to a management decision to examine alternative methods and systems for system monitoring, control and dispatch. This is often accomplished by appointing an internal task force or study group to examine the problems as well as potential solutions, including expected benefits and costs. Such studies can be realized by the use of a consultant qualified in control center planning. The use of a consultant lowers the utilities risk in acquiring an adequately prepared study. It also aids in overcoming problems in having the personnel available to perform the study.

The need for new or modified control systems may be based on:

- Outmoded systems
- Requirements for additional supervisory control
- Requirements for automatic generation control
- Requirements for expansion
- Requirements for system security monitoring
- Potential economic savings

When the Borrower management has concluded that some form of new or improved control system is appropriate and justified, a requirements study can be initiated which broadly outlines the total project. These studies establish the broad scope of the project, including major functions to be performed, heirarchial system arrangement, control center location(s), building requirements, schedule, budget estimates and staffing requirements.

Major objectives during this planning period are to:

- Plan for a quality system which performs as anticipated early in its life cycle
- Minimize system life cycle costs consisting of:
  - initial costs
  - future growth and expansion costs
  - operating costs
- Minimize risk

The results of a requirements study are documented in a report which forms the basis for subsequent development of a system procurement specification.

The following outline is typical of the information to be obtained and representative of most Borrower study requirements:

1.0 <u>INTRODUCTION</u>

- 1.1 Scope of Study
- 1.2 Study Goals
  - 1.2.1 Control Philosophy
  - 1.2.2 Communication Requirements
  - 1.2.3 Project Implementation Personnel
  - 1.2.4 New Applications
  - 1.2.5 Backup Schemes
  - 1.2.6 Man/Machine Considerations
  - 1.2.7 Project Schedule
  - 1.2.8 Project Costs
  - 1.2.9 Facility Requirements
- 1.3 Study Operation Procedures
  - 1.3.1 Documentation Review
  - 1.3.2 Planning and Specifications Guide
  - 1.3.3 Field Visits
  - 1.3.4 Design Meetings
  - 1.3.5 Other Applications
- 1.4 Report Structure

2.0 <u>REQUIREMENT FOR A COMPUTER SYSTEM</u>

- 2.1 New Responsibilities
- 2.2 Benefits of a Modern System
- 2.3 Conclusions

3.0 <u>SYSTEM FUNCTIONS</u>

- 3.1 Economic Dispatch
- 3.2 Interchange Scheduling
- 3.3 Supervisory Control and Data Acquisition
  - 3.3.1 On/Off Control
  - 3.3.2 Control of Transformers
- 3.4 Data Processing
  - 3.4.1 Meter Error Analysis
  - 3.4.2 MVA Calculation
- 3.5 Data Logging
- 3.6 Load Shedding and Restoration
- 3.7 System Peak Analysis
- 3.8 Energy Accounting
- 3.9 Disturbance Analysis

7.0 STAFFING AND TRAINING

- 7.1 Project Staffing and Personnel
  - 7.1.1 Project Manager
  - 7.1.2 Engineering Support
  - 7.1.3 Operations Support
  - 7.1.4 Programming
  - 7.1.5 Maintenance
  - 7.1.6 Consultants
- 7.2 Permanent System Staffing
- 7.3 Training
  - 7.3.1 Hardware Maintenance Courses
  - 7.3.2 Software Courses
  - 7.3.3 Dispatcher Training

8.0 FACILITY CONSIDERATIONS

- 8.1 Physical Characteristics
  - 8.1.1 System Control Room
  - 8.1.2 Equipment Room
  - 8.1.3 Conference and Visitor Facilities
  - 8.1.4 Programming Facility
  - 8.1.5 Office, Maintenance, and Storage Facilities
  - 8.1.6 Power Supply Area
- 8.2 Security
  - 8.2.1 Area Access
  - 8.2.2 Smoke and Fire Protection
- 8.3 Environment Characteristics
  - 8.3.1 Air Conditioning
  - 8.3.2 Acoustics
  - 8.3.3 Lighting
  - 8.3.4 Electrical Interference
- 8.4 Power Conditioning
  - 8.4.1 Power Supply
  - 8.4.2 Grounding
- 8.5 Communications
  - 8.5.1 Data Channel Requirements
  - 8.5.2 Voice Communication Requirements
  - 8.5.3 Alternate Communication Facilities

9.0 COST ANALYSIS

- 9.1 Master Station Costs
  - 9.1.1 Hardware and Software Purchase Costs
  - 9.1.2 Costs of Additional Services
  - 9.1.3 Building Costs
- 9.2 Options
- 9.3 Remote Site Costs
  - 9.3.1 Remote Terminal Units

APPENDICES:

A - Definitions

B - Representative CRT Displays

C - System Configuration

D - Data Acquisition and Control Requirements

E - Communication Channel Requirements

F - Cost Elements

G - Inter-Utility Data Exchange

J. Elements Of A Control System Specification

A procurement specification is used to solicit technical and price bids from potential system suppliers. To facilitate preparation of system proposals which truly reflect the needs of the utility, a high quality specification is essential. The specification defines the required system, preferably in functional terms, as well as various supporting services, and terms and conditions. The specification should be designed to encourage bids from qualified suppliers using their standard hardware and software modules where these will satisfy the requirements.

It is necessary, in order to acquire a cost effective and well performing system, to prepare a high quality specification. Specifications for these systems are prepared in close coordination with the utility project task force. The output of a previous requirements study forms the basis for the specification. Additional on-site data gathering is also normally performed. Individual sections of the specification are then assembled in draft form, and submitted as they are prepared to the project team for review and comment. Comments are incorporated on a continuous basis until a final review is made of the entire specification. Following final review and incorporation of desired changes, the specification is published and made available to potential system suppliers in the form of a Bid Package. A representative outline used for a control system specification is provided at the end of this section.

In some situations it is more cost effective to combine the requirements study and the specification preparation. In these situations, a supplementary document is prepared which contains information valuable to the utility but not appropriate for inclusion in the specification. Information typically found in the supplementary document includes:

- Building and facility requirements
- Staffing and training recommendations
- Overall project schedule and implementation plan
- Project management recommendations
- Definitive budget estimates.

The following outline is typical of the information and organization of a control system specification that incorporates both the SCADA and Energy Management System (EMS) function.

4. <u>System Requirements</u>

4.1 System Data Flow
4.2 System Configuration

4.2.1 Communication Channel Assignment

4.3 Availability

4.3.1 System Availability
4.3.2 Mean-Time-To-Repair
4.3.3 Final Acceptance Demonstration Availability
4.3.4 Availability Analysis

4.4 Redundancy/Failover Criteria

4.4.1 Computer Complex and Peripherals
4.4.2 Man/Machine Interface
4.4.3 Master Failover
4.4.4 Power Supplies

4.5 System Interactive Man/Machine Response
4.6 Data Scanning Rates
4.7 Communications

4.7.1 Communication Channels
4.7.2 Communications Security

4.8 System Expansion
4.9 System Analysis

5. <u>Hardware Requirements</u>

5.1 Computer Subsystem

5.1.1 Central Processing Unit (CPU)
5.1.2 Direct Memory Input/Output System
5.1.3 Main Memory
5.1.4 Mass Memory
5.1.5 Priority Interrupt System
5.1.6 Computer Console
5.1.7 CPU/CPU Channel Interface
5.1.8 Watchdog Timers
5.1.9 Keyboard/Printer
5.1.10 Card Reader
5.1.11 Power Fail-Safe
5.1.12 Device Controllers
5.1.13 Expansion

5.2 Man/Machine Subsystem

- 5.2.1 Operator's Console (EMS Control Center)
- 5.2.2 Operator's Console
- 5.2.3 Special Man/Machine Equipment
- 5.2.4 Display Generation, CRT and Keyboard Equipment
- 5.2.5 Operator and Alarm Loggers

5.3 Communication Subsystem

- 5.3.1 Data Channel Multiplexers
- 5.3.2 Data Channel Controller
- 5.3.3 Communications Modems
- 5.3.4 Communication Jack Panel

5.4 Remote Terminal Units

- 5.4.1 Data Acquisition
- 5.4.2 Supervisory Control
- 5.4.3 Communication
- 5.4.4 RTU Design Characteristics
- 5.4.5 Expansion and Growth
- 5.4.6 Input/Output Interface Definition
- 5.4.7 RTU Portable Test Set

5.5 General Design and Construction Requirements

- 5.5.1 Equipment Racks
- 5.5.2 Special Test Equipment and Maintenance Tools
- 5.5.3 Workmanship
- 5.5.4 Service Life
- 5.5.5 Equipment Enclosures
- 5.5.6 Personal Safety Design
- 5.5.7 Maintainability Design
- 5.5.8 Human Engineering
- 5.5.9 Logic Modules
- 5.5.10 Power Supplies
- 5.5.11 Wiring
- 5.5.12 Connectors and Terminal Strips
- 5.5.13 Cables
- 5.5.14 Heat Dissipation
- 5.5.15 Name Plates and Product Markings
- 5.5.16 Electomagnetic Interference (EMI)
- 5.5.17 Environmental Conditions
- 5.5.18 Shock and Vibration

5.6 Facility Requirements

6. Software Requirements

6.1 The Operating System

6.1.1 General Requirements
6.1.2 Real-Time Scheduler
6.1.3 Program Security
6.1.4 System Surveillance and Failover
6.1.5 I/O Control and Processing
6.1.6 System Initialization

6.2 Communications Software

6.2.1 Data Scanning and Security Checking
6.2.2 Party Lining and Message Efficiency
6.2.3 Data Conversion and Limit Checking
6.2.4 kWh Data Acquisition

6.3 System Data Base

6.3.1 Data Coding
6.3.2 Real-Time Data Base
6.3.3 System Parameter Data Base
6.3.4 Results Files
6.3.5 History File
6.3.6 Alarm and Abnormal Status File
6.3.7 Data Base Generation and Updating

6.4 Man/Machine Software

6.4.1 CRT Displays
6.4.2 Console Keyboards
6.4.3 Logger/Printers

6.5 Programmer's Aids

6.5.1 Standard Assemblers and Compilers
6.5.2 Data Base and CRT Picture Generation and Updating
6.5.3 Utilities

6.6 Application Software Requirements

6.6.1 System Monitoring
6.6.2 System Alarming
6.6.3 Supervisory Control and Tagging
6.6.4 Log and Report Generation
6.6.5 Load Forecast File Program
6.6.6 Background Processing
6.6.7 Future Power System Applications

7. <u>Supporting Services</u>

7.1 Documentation

7.1.1 System Design Specification
7.1.2 Hardware Documentation
7.1.3 Software Documentation
7.1.4 System Operation and Maintenance Manuals
7.1.5 Program Documentation
7.1.6 Document Changes
7.1.7 Documentation Submittal
7.1.8 Final Documentation Submittal

7.2 Training
7.3 Maintenance Plan and Spare Parts
7.4 Project Coordination and Mangaement

8. <u>System Implementation and Acceptance</u>

8.1 Program Schedule
8.2 Equipment Delivery Points

8.2.1 EMS Equipment
8.2.2 RTU Equipment

8.3 Supplier and Purchaser's Responsibilities

8.3.1 System Design, Fabrication, Tests and Delivery
8.3.2 Design Reviews
8.3.3 Documentation
8.3.4 Installation and Integration
8.3.5 Tests and Demonstrations
8.3.6 Training
8.3.7 Quality Assurance
8.3.8 System Activation
8.3.9 Performance Warranty

8.4 Test and Acceptance Requirements

8.4.1 Subsystem and System Testing
8.4.2 System Acceptance Tests
8.4.3 Test Plans and Procedures
8.4.4 Other Test Data Reporting
8.4.5 Standard Test Equipment

9. Instructions To Bidders

9.1 General

9.1.1 Intention to Bid
9.1.2 Proposal Due Date
9.1.3 Proposal Delivery

9.2 Proposal Acceptance

9.2.1 Technical Proposal Structure
9.2.2 Pricing Proposal

9.3 Proposal Evaluation
9.4 Questions and Coordination
9.5 Bid Documents
9.6 Award of Contract
9.7 Disposition of Proposal Documentation

10. Terms and Conditions

10.1 Definitions
10.2 Engineer's Status
10.3 Time of Commencement, Prosecution, and Completion
10.4 Prices and Method of Payment
10.5 Warranty
10.6 Precedence
10.7 Acceptance
10.8 Progress Reports
10.9 Performance Bond
10.10 Changes
10.11 Shipment
10.12 Notice of Shipment
10.13 Title
10.14 Default
10.15 Subcontracts
10.16 Origin of Components
10.17 Compliance with Laws, Ordinances, Rules, and Regulations
10.18 Liens
10.19 Indemnity and Insurance
10.20 Risk of Loss
10.21 Force Majeure
10.22 Patents
10.23 State Law Governing Contract
10.24 Assignments
10.25 Provisions Relative to Employment
10.26 OSHA Compliance

V. COST ANALYSIS

A. General

This section presents costs for preparation of plans, studies, and specifications; designing, installing, and implementing the system; system hardware and software.

The costs represent composite averages based on a review of 30 contracts and discussions with six manufacturers.

All cost estimates are based on 1979 dollars and are rounded off to the nearest $1,000. An allowance for inflation to cover the period between the date of this document and the actual signing of a contract should be included in the final budget figures prepared by the borrower.

After determining the functions and design goals to be satisfied by the supervisory control and/or energy management, it is necessary to configure the proposed system accordingly.

Within the framework of the cost analysis section, three such possible configurations are discussed: (1) single processor CPU, (2) dual processor CPU, and (3) dual processor CPU's with preprocessors. While these are not the only configuration possibilities in a given control system design, they are the most fundamental and certainly the most prevalent.

The next paragraphs of this section briefly discuss the three configurations in terms of how system functions and design goals are satisfied, the hardware and software involved, and the advantages and disadvantages of each. The costs associated with each configuration are also provided.

B. Common Configuration Characteristics

There are certain attributes which are considered basic to meeting most systems design objectives, and are, therefore, common to all systems discussed herein. The configurations are discussed in depth in subsection C - Operational Configuration. In the description of each configuration the performance criteria of individual components should be specified only to the degree necessary to insure the achievement of minimum acceptable levels of system performance. Performance parameters of individual system elements should be specified only when they are critical to overall system performance.

1. Common Hardware

A minimum level of redundancy is required in any viable

configuration to achieve high reliability and not subject performance to the failure of a single element. This requirement would not be satisfied by the single CPU configuration shown in Figure V-1. This system is described herein because it can fulfill almost all functional requirements, and it is the fundamental systems building block although its low availability may render it unacceptable. The remaining systems are redundant CPU configurations which are more desirable from a reliability standpoint. The auxiliary memory and CRT's have also been shown in two configurations: nonredundant and redundant with dual port interfaces. The reliability of these three critical components, the CPU, auxiliary memory and CRT's, their failover capabilities and their implementation in the system configuration will be of prime importance in the evaluation of a Vendor's offering.

An analysis of system tasks and their desired timing will yield the requisite word size 'minicomputer' as the CPU. Vendor offerings will include machines with word sizes of 16 bit, 24 bit, and 32 bit machines and 16 bit CPU's capable of handling 32 bit and 64 bit data words. The preferences of individual Vendors in their selection of processors has made the specification of a specific word size unrealistic. More important is the arithmatic capability of the machine offered. Each Vendor proposal should be evaluated on its functional capabilities as well as other factors mentioned herein. The pricing work sheets shown in Appendix C may be used for proposal evaluation.

All configurations contain a common set of recommended control system peripherals:

- o KSR - one KSR (teletypewriter or CRT with hard-copy) per CPU for processor communication and program control and development.

- o Line Printer - one medium speed (200 to 400 lines per minute) line printer for program listing, large logs and as a back up device for the loggers.

- o Magnetic Tape Deck - for program storage, input and long-term data storage.

- o Loggers - two logging typewriters (120 cps) should be included for alarm logging, event recording and small to medium size logs. Normal operation will find each logger dedicated to specific functions, with failover to each other or the line printer.

- o Recorders - several dual pen recorders and single pen recorders should be provided for hard copy trending. Half of the two pen recorders may be assignable to any variables in the data base, the remainder may be dedicated.

- o Indicators - several four digit numeric indicators are to be provided. All indicators are assignable.

Two operating consoles are considered basic to most systems. The Control Operator's Console, located in the control room, includes two CRT's, two keyboards, and two associated function panels.

A second console, the Programmer/Training Console, is located in the computer room. This console is identical in configuration and function to the Control Operator's Console and can be used for development, debugging, training or as a second Operator's Console in stress or failure situations.

Local I/O to interface indicators, panel lights, and analog telemetry equipment is provided through dedicated I/O equipment designed for local inputs, or on the configuration drawings, through an RTU located in the ECS.

Table V-1 is a list of peripheral hardware common to all three configurations.

2. <u>Common Software</u>

The exact description of the software to be supplied with the system is highly machine, and therefore Vendor dependent. To briefly describe the software common to the configurations, the system has been broken into generalized programs or program groups. Software provided by any Vendor can be expected to follow the general outline offered below. Table V-2 is a list of software common to all three configurations. Experience has shown that the use of a consulting firm for the purpose of specifying, designing, and/or evaluating Vendor software offerings has not only proven cost-effective but almost imperative in complex operating structures.

a. <u>Basic Software</u>

This package includes the system 'executive' or resource management software, peripheral failover routines, machine failover routines for the dual CPU configurations, scheduling algorithms, device handlers for the computer peripherals and CPU to CPU data links,

and the software for the interactive CRT I/O.

b. Data Base, CRT and Log Format Generation

This software allows the user to add, delete, or modify entities within the ECS to reflect changes in the electrical network.

c. Data Collection

This package assembles the real time data base by polling the data collection RTU's for both scheduled and demand requests. Data received is checked for validity, converted to engineering units, and stored in the data base.

d. Generation Control and Application Software

The required system functions, described in Section III.C and Appendix A, are performed by this software. Each function is performed by routines which the Vendor has implemented from a standard library of application programs, or where a new or different requirement has been imposed, by software written expressly for this project.

e. Communications Software

These specialized programs are required to provide interconnected facilities with real time control data and detailed historical data for billing and planning.

f. Diagnostic Software

This package is comprised of a set of diagnostic programs for each hardware component of the control system. Where possible on-line diagnostics are required to enable maintenance to proceed in parallel with system operation. Off-line diagnostics are provided for those devices, such as main-memory, whose failure implies part of the system be placed off-line.

g. Background Processors

This software allows performance of normal software maintenance, update and test, as well as generation, compilation, test, and initialization of new programs.

3. RTU Installations

Cost comparisons between analog/KWH digital tone telemetry and remote digital multiplexing through the facilities of a Remote Terminal Units (RTU) show: For larger stations the RTU, a device which serially transmits strings of analog and status data words over a single voice grade communications channel, proves to be more economical. This economy is observed in hardware costs; the cost of an RTU ranges from $3,000 to $20,000 depending upon the number of points or control options performed. The development of new, small, "pole top" RTU's, devices functionally identical to standard RTU's but of limited capability, with prices equal to or less than comparably sized telemetry tone equipment, has made the utilization of RTU's for the smallest meter points economically expedient.

To facilitate cost estimates, four basic RTU configurations are discussed:

- o Bulk delivery substations
- o Bulk delivery line taps
- o Meter points
- o Generation sites

The descriptions below are sized for typical station configurations and do not include provisions for implemented or nonimplemented spare points. Table V-3 provides costs for various sized RTU's.

RTU for bulk delivery substations:

- o 20 control outputs - 8 breakers, 8 recloser blocking controls and 2 LTC's

- o 8 momentary change detection inputs for reclosing breakers

- o 30 status inputs - 8 supervisory blocking switches, 8 recloser blocking switches, 8 transformer alarm contacts, and 6 miscellaneous points

- o 8 analog inputs - kV, MW, MVAR, and LTC positions

- o 4 accumulator inputs - MWH and MVARH

RTU for bulk delivery line taps:

- o 2 control points - 1 breaker and 1 recloser blocking
- o 1 momentary change detection input
- o 8 status inputs - 1 supervisory blocking, 1 recloser blocking, and 4 miscellaneous points
- o 2 analog inputs - MW, MVAR
- o 2 accumulator inputs - MWH, MVARH

RTU for meter points:

- o 4 status inputs for miscellaneous alarms
- o 2 analog inputs - MW, MVAR
- o 2 accumulator inputs - MWH, MVARH

RTU's for generation sites are developed individually due to the differences among plants.

To minimize the initial system cost RTU's should be standardized as much as possible to reduce the Vendor's engineering charges. Units should also be sized to include later changes if a meter point is to be upgraded to a bulk delivery point. Evaluation of Vendor proposals should include determining the economics of upgrading a meter point RTU to one of the larger configurations. Additional criteria includes:

- o Maximum size of a 'pole top' or mini-RTU
- o Cost comparison of mini and standard RTU's
- o Acceptability of utilizing two or more 'pole top' units to control a single substation
- o Component compatability between standard and mini-RTU's
- o Use of remote data concentrators of 'report-by-exception' RTU's to relieve communications channel bandwidth usage

4. <u>RTU Communications</u>

Communications to RTU's located at substations or

generation stations may be via voice grade communication circuits, microwave LOS, or power line carrier of a rate of 1200 bits per second. In order to reduce the number of required circuits, RTU's may be 'party-lined' where possible, i.e. more than one RTU may be connected to each circuit. This loading allows sufficient free time for the control system to retrieve the remaining data at slower scan rates and perform control operator initiated control actions. Line loading can be increased to 8 or 10 RTU's per circuit if a circuit contains 4 or more of the small RTU's described above as bulk delivery line tap or meter point RTU's. Vendors should be asked to detail their expected bandwidth usage and the potential of their equipment to operate at a higher bit rate (greater than 1200 bps) to increase channel efficiency with a corresponding reduction in operating costs.

5. Optional Equipment and Software

A variety of options have been defined which are applicable to any of the following configurations. The options are to enhance system expansion capability or to improve the operating capabilities of the control system. Table V-4 lists each option and its estimated costs. These options should be described in detail in the specification. Their incorporation into the control system will be based on their cost-effectiveness as determined during bid evaluation. The following is a brief description of each optional hardware item:

a. CRT Hardcopy

The basic system will provide hardcopy records of all alarms, System Controller actions and data entries as they occur, and predefined logs of operations and study results. Unique power system conditions can be recorded if the system can also provide hardcopy of CRT displays on demand. This option should include the capability of hardcopy (in black and white) for one-line diagrams.

b. Dynamic Mapboard Interface

This option will provide for an interface to drive the indicators of a system mapboard. The mapboard, if implemented, will be purchased separately. For bidding purposes the specification will contain the number and type of indicators, and a description of their operation.

c. Single CRT Console

This option will provide a limited capability console for nonoperator use. If purchased it will be used as a programmer/training console. The console will be similar in design to the two CRT consoles, but contain a single CRT, keyboard, and function panel. The telecommunications facilities would be minimized, including only a simple pushbutton handset. Writing space and drawers are required but may also be reduced in scope from that required by a Dispatcher Console.

d. Redundant Keyboard/Function Panel

To allow two Dispatchers to simultaneously operate from a single two CRT console, this option would add a second keyboard and function panel to the console equipment. A switch matrix would allow either keyboard to access and control both CRT's, or dedicate each of the keyboards to a single CRT.

6. Software Maintenance and Development

Software maintenance is chiefly concerned with the adding of new substations and dispatch units, or new points at existing substations, specifying CRT schematics and devising more pertinent reporting formats. If only a single programmer is to be employed, the system is highly vulnerable to a loss of his services. Programmers tend to find routine maintenance work dull and unrewarding. If the system is to be a dynamic entity, many opportunities exist for the development of sophisticated monitoring techniques and analytical tools which not only assist the control operator in pinpointing trouble conditions but also delineate possible courses of action. No manufacturer can provide such programs; borrower programmers and engineers with knowledge of their own electric system are best suited to develop these practical tools. Data storage, documentation and dissemination is also a field where every borrower has unique requirements. The system can provide valuable assistance to other departments within the company by gradually developing programs tailored to the information storage and retrieval needs of the company.

Routine software maintenance should not require downtime. The generation of a new schematic, for example, should be done via programmer's I/O devices, Even if no immediate plans for program development are in evidence, the purchased systems should be fully capable of future

expansion. This cannot be assured unless these tools are planned for and tested in the initial system.

7. Hardware Maintenance

A complete set of master station and RTU spare parts should be stocked at the facility. Tools in the form of adequate test equipment, diagnostic programs, and thorough training of personnel at the Vendor's factory, are requisite to maintaining system integrity and initial operating performance.

Successful and continuous operation of the system depends on routine maintenance under an effective preventive maintenance program. Replacing air filters, checking cooling fans, cleaning cabinets, checking hardware parameters and operating temperatures, maintaining discs and adjusting and lubricating electro-mechanical peripherals are activities which must be performed regularly if the system is to perform with a minimum of downtime. The computer should generate for the use of hardware maintenance personnel a periodic summary list of failed equipment and equipment with high error counts.

The system should be purchased with built-in hardware checks. Test panels and customized test sets, as available, should also constitute part of the system. Hardware documentation consisting of physical and electrical plans of cabinets, consoles, and peripherals, maintenance manuals, instruction books, reference manuals, installation wiring diagrams and related drawings should be stored at the central location in an orderly manner.

8. Man/Machine Interface

Reliable operation of the system requires a comprehensive method for system dispatchers to interact with the power system. Errors can result in overloaded lines, damaged equipment and customer loss of power. The recommended configuration based upon study and analysis will provide system dispatchers with an interface commensurate with their responsibilities.

A single control operator's console, with redundant CRT's, keyboards, and function panels, and operating space for two men, will prove sufficient for most systems initial implementation.

A facility duplicating the control operator's interface is recommended for use by the programming personnel. The addition of new RTU's, new points, new displays, and

modifications to existing displays will be routine daily system activities. The implementation and testing of these additions and changes should not rely on the control operator's facilities. These tasks can be handled efficiently on separate devices removed from the operating environment. Since many control operator interfaces can be duplicated in this subsystem, trainees may become familiar with all control system functions without disturbing normal control operator duties. The programmer/ console can also serve as an additional control operator console during periods of system disturbance.

All CRT displays should utilize color. Formats may be alphanumeric, limited-graphic or a combination of both. System parameters and devices should be appropriately identified on each display. Dynamic single line substation diagrams may be used to support swift, quiet and efficient operation.

A static mapboard showing the system control operator dispatches the updated status of the overall network is recommended. The expenditure to automate mapboard indications should be ascertained during the time trail procurement. Vendors should be required to price this option for possible enhancement of the system.

Recorders are needed and recommended to display system frequency, area control error and intercompany power flows. These recorders will provide the control operator with a continuous record of the major system parameters. Additional recorders and digital indicators may be required for display of control operator assigned parameters to observe trends or analyze short-term phenomena.

9. Engineering and Implementation Services

The tasks shown in the following Table V-5 must be performed regardless of the configuration selected to assure adequacy of the design, prepare for and complete installation, and to test the equipment, both before and after delivery, for conformance with the specification requirements. The costs for the engineering tasks are fairly constant for all the configurations evaluated. Similarly, the costs for purchased services do not vary significantly with the system configuration. The following descriptions summarize the various engineering and implementation tasks shown in Table V-5.

a. Preparation of Specification

This item includes the use of two senior engineers for

the preparation of functional specifications, the evaluation of Vendor proposals and contract negotiations with the selected Vendor.

b. Software Monitoring, Programming and Training

The estimate assumes that one programmer will be added at the beginning of the project implementation phase, and that the equivalent of a full-time engineer will work in this area. This staff will review all Vendor software design and provide the supporting data for the application programs. Attendance at training courses and system testing are also included in this item. System test includes participation in the Vendor's factory test and final acceptance tests at the borrower's facility.

c. Hardware Monitoring, Power System Engineering and Training

This activity will be performed by the equivalent of a full-time engineer, beginning with the project implementation phase. It includes review and approval of design approaches and providing the necessary power system and communications data to the Vendor. Attendance at training courses and system test are also included in this item. Costs are included for two hardware maintenance technicians to attend the Vendor's hardware courses for approximately three months. These maintenance men will participate in the factory and field acceptance tests. The engineer will attend basic training courses only and supervise the conduct of all tests.

d. System Controller Support and Training

This item represents the involvement of a control system engineer in the design review and approval of the control system man/machine interface.

e. Installation

This item is the estimate of the work performed by personnel in the installation of equipment at the borrower's facility. The wiring and related tasks at the center may be purchased from a Vendor or wiring contractor or performed by borrower personnel. The estimate assumes that the system Vendor will provide supervision for system installation and start-up by borrower personnel. The estimate covers

manpower to supplement the two maintenance technicians covered in the items above.

f. Factory and Field Acceptance

The task involves witnessing factory and field acceptance and availability testing. Included is the cost of the final update and check out prior to availability testing.

g. Training

This item includes the Vendor's charges for training courses given by him or subcontractors. Hardware, software, and system controller training is included.

h. Documentation

The Vendor's cost for the preparation and production of all manuals and drawings is covered in this item.

i. Freight and Insurance

Costs for packing, shipping, and insurance coverage while in transit and on-site prior to acceptance is estimated in this item.

j. Engineering Services

This item covers the costs of the Vendor's lead project engineers who are responsible for the technical integration of the project including system design, detailed specifications and test plans.

k. Project Management

The Vendor can be expected to assign a full-time manager to a project of this scope to perform internal scheduling and budgeting activities and to serve as liaison with the borrower from the signing of the contract to completion of the availability test. Design liaison with the architect/engineer of the control system facility to house the system is included in addition to computer system design and contract monitoring.

l. General and Administrative

This item includes costs to be incurred by borrower personnel not normally associated with the technical aspects project. This item will cover purchasing

costs, accounting, and administrative charges.

10. Master Station

Tables V-6 through V-8 illustrate budgetary costs for the systems shown in Figures V-1 through V-3; that is, a single CPU, dual CPU's, and dual CPU's with preprocessors. As with all costs given herein, care must be exercised in their use. The costs should be used for budgeting purposes only and not as a tool for evaluating bids. This is especially the case for the items shown in Tables V-1 through V-5 since none of these items represent discounted prices or the results for a negotiated bid. To attempt to apply such factors would result in many small systems being over-budgeted while the medium to large scale systems are under-budgeted.

For example, for systems having a large number of RTU's, the master station prices will tend to be discounted or represent a lower cost element. Whereas for those systems having a small number of RTU's and significant applications software, the master station will represent the largest cost (and profit) and would be the least discounted.

Two other factors which also have a large impact on cost are the CRT update time and the frequency of execution of applications software. If these two factors are to be executed frequently, for example, update a CRT page every two to three seconds and execute a large number of application software programs every four to fifteen seconds, the CPU's and auxiliary memory sizes will have to be increased or preprocessors added. The end result is increased costs.

Additionally if the standard software packages offered by the Vendors require extensive modification software costs may double or even triple. As stated earlier Tables V-6 through V-8 are typical costs and have a broad application to a large number of REA systems.

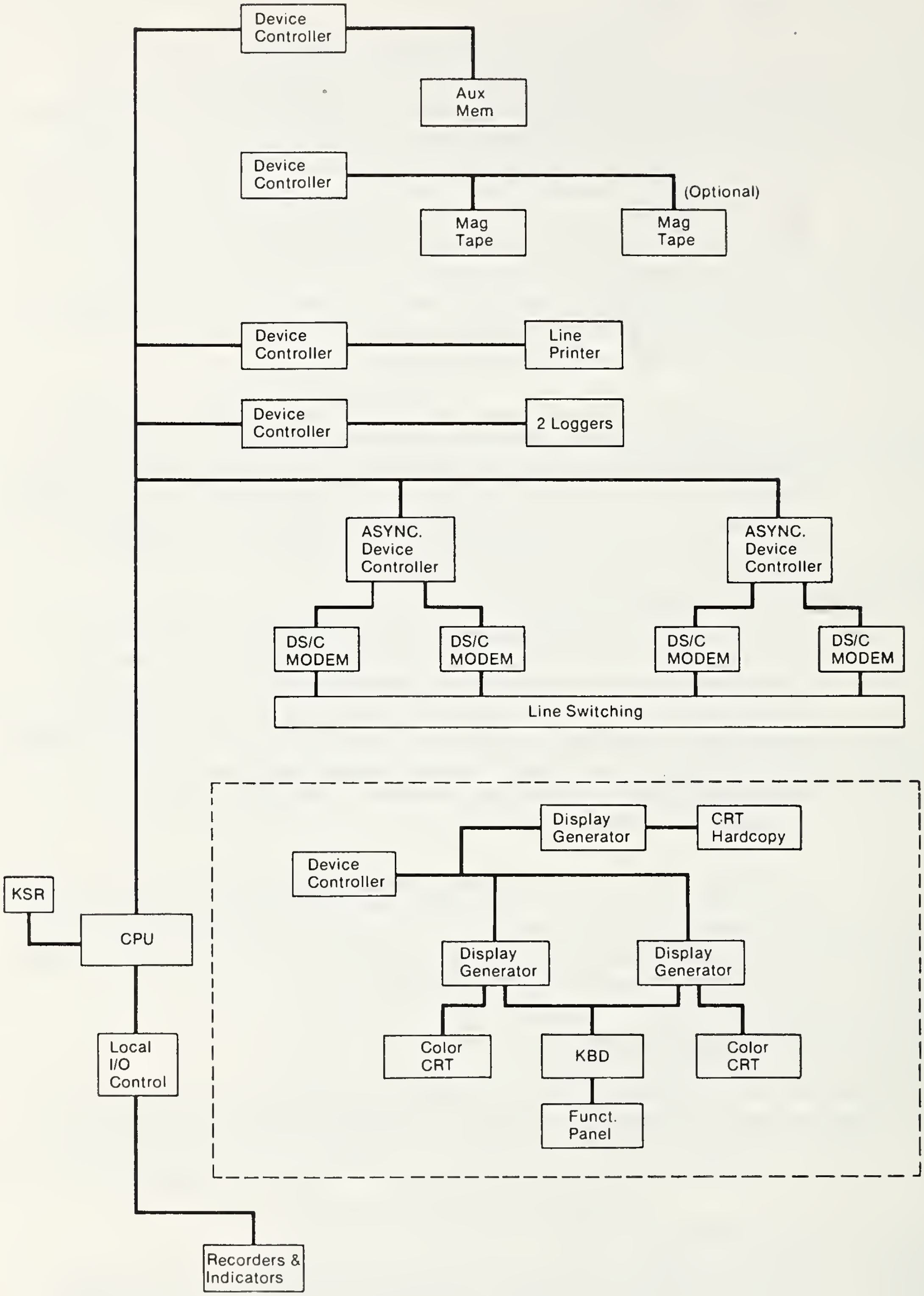
C. Operational Configurations

The following paragraphs provide descriptions of three common operational configurations used in supervisory and energy control systems. The costs for the master station configurations 1, 2, and 3 are given in Tables V-1, 7, and 8 respectively.

1. Configuration 1

This arrangement, shown in Figure V-1, is a basic system configuration which does not have a high level of system

Figure V-1 Single Processor Configuration



availability but has been shown here for reference purposes only. A single CPU is utilized. Attendant with the CPU is a KSR device for programmer communication. High speed peripherals, the auxiliary memory, magnetic tape, line printer, loggers, and the console equipment, are interfaced via the computer Input/Output Processor (IOP). The communications control is also shown interfaced through the IOP. Slow speed devices such as the recorders and indicators, may be interfaced through single work I/O ports, or through a local RTU.

a. Operation

All foreground and background programming tasks are performed by the CPU. Background performance may be degraded in times when major network emergency or contingency operations force a high usage of CPU resources to cope with the control system requirements. Redundancy is minimal; the loggers can fail over to each other, or to the printer. A single CRT failure will not degrade system operation. Two keyboard/CRT configurations are available by switch selection.

(1) Advantages

(a) This is the lowest cost system which may meet certain basic functional requirements.

(b) Maintenance and personnel costs are lower since this system utilizes a single CPU.

(c) Development risk for the basic system, excluding options, will be low since the configuration is compatible with that offered by many Vendors.

(d) Expansion increment available by upgrading to configuration.

(2) Disadvantages

(a) Growth in terms of new application programs are limited due to the CPU loading imposed by the basic functions.

(b) System operation can be halted by the failure of a single component.

(c) This system will have the lowest expected availability (less than 98% or approximately 3.5 days downtime per year).

(d) Background programming capability is restricted since the CPU will carry a sizable computational load. Compilation and assembly of large programs would be tedious and costly.

(e) Certain background functions (system generation, data base generation) may require taking the system off line.

(f) As the system expands, responsiveness to Dispatcher inputs could be degraded as computational resources become heavily loaded.

(g) New functions, when available, may be difficult to implement without procurement of main memory increments.

2. Configuration 2

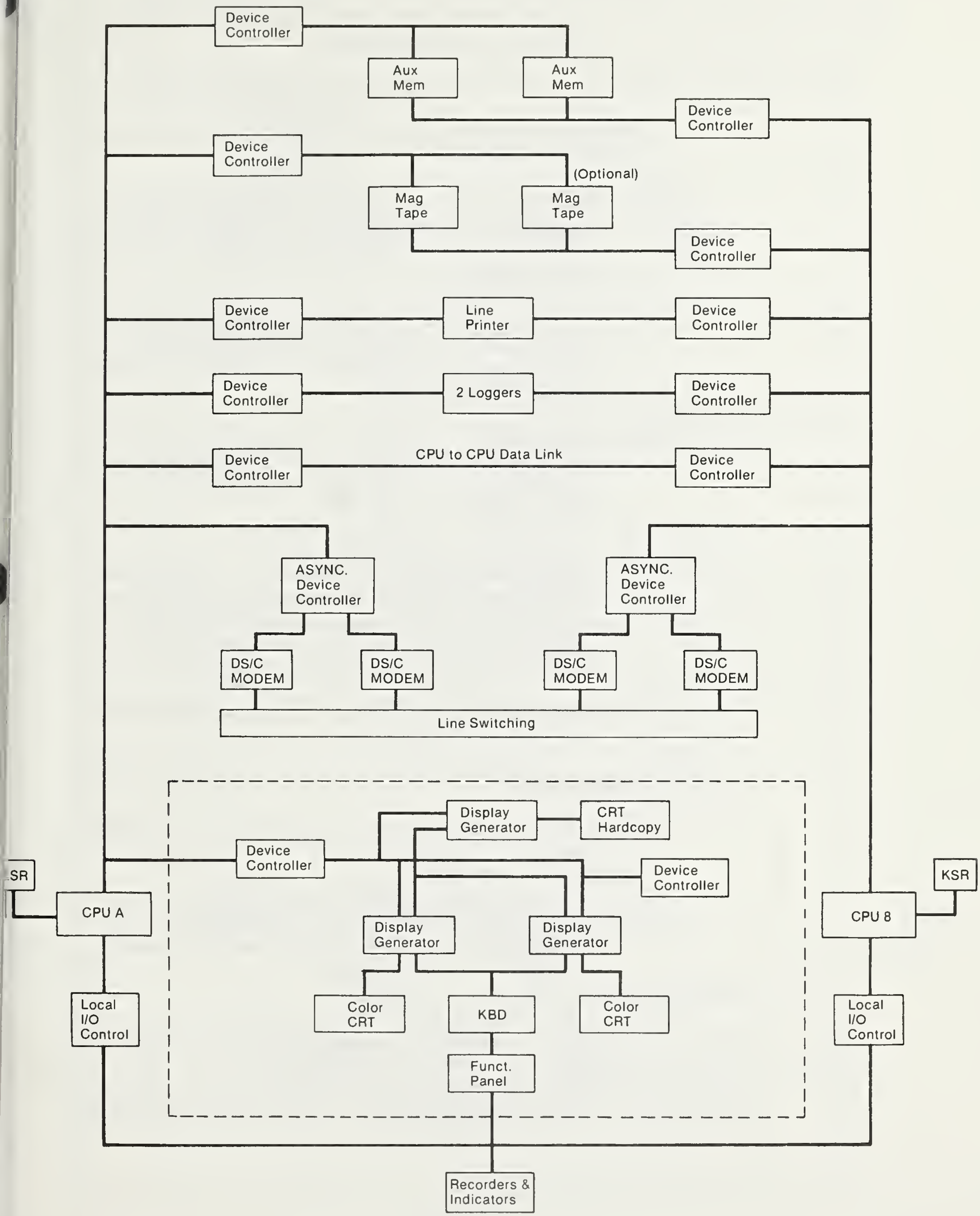
This system, described by Figure V-2 provides a redundant CPU and auxiliary memory to the basic configuration. All peripheral devices are dual ported to allow access by either processor. A CPU to CPU link is included for direct, high speed interprocessor communication.

a. Operation

One of the CPU's is designated as the prime computer and the other backup. Control of the power system will be exercised by the prime CPU. The backup machine will be available to take control in the event of failure of the prime. The prime will periodically provide an output of the system data bases to the backup computer auxiliary memory so that failover will cause minimal discontinuity in operation. Access to peripheral devices is controlled by hardware and software to prevent simultaneous access to any device by both CPU's, or, in the case of a failure, to prevent the failed CPU from locking out the backup CPU from any peripheral.

The backup machine will normally be available for background programming. Each CPU would be sized to be able to carry the full foreground computational load with little or no loss of capability when forced to operate in a single CPU configuration. Background processing will be sharply degraded in the single CPU mode.

Figure V-2 Dual Processor Configuration



(1) Advantages

(a) Can fully meet most rural electric system functional requirements.

(b) No functional degradation during failure.

(c) Significant background computational resource is available.

(d) New functions can be incorporated without significant software changes and, in most cases, without the need to purchase additional core memory.

(e) Maintenance and personnel costs are moderate (more than Configuration 1, but less than Configuration 3) since this system involves two identical CPU's.

(f) Development risk for both the basic system and optional functions is low since the configuration is similar to that offered by many Vendors.

(g) Programmers need to be familiar with only one operating system and set of programming languages. Company programming efforts may be minimized by the use of sophisticated language processors, data management and trouble-shooting debugging procedures.

(h) Availability is expected to be about 99.8% per year or better.

(2) Disadvantages

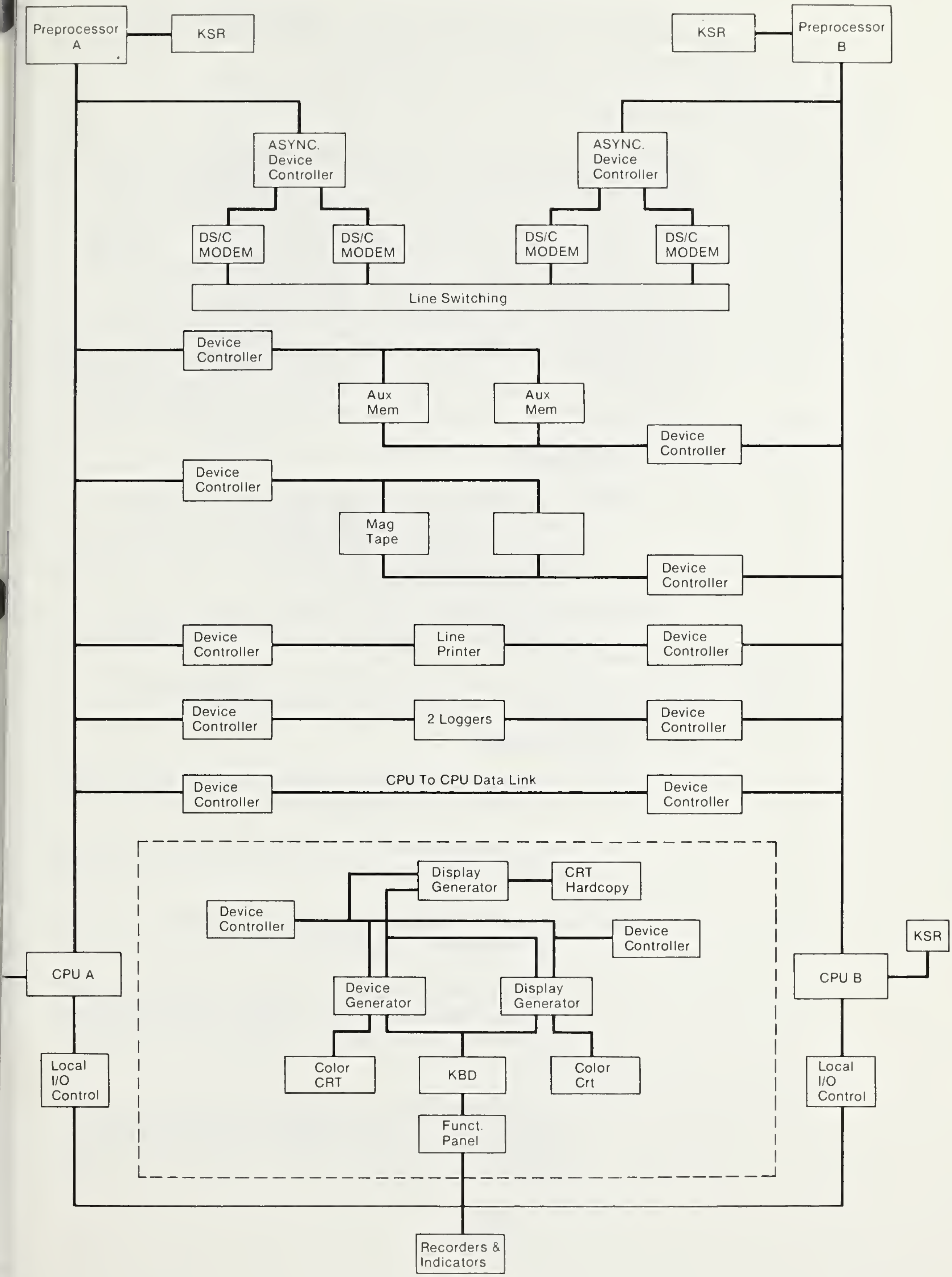
(a) Initial system cost is higher than Configuration 1.

(b) As the system expands, responsivensss to Dispatcher inputs could be degraded as computational resources become heavily loaded.

3. Configuration 3

This system, shown in Figure V-3, introduces two additional CPU's to the redundant system of Configuration 2. The new CPU's are used as preprocessors to relieve the main processors of some of their tasks. This system illustrates

Figure V-3 Dual Processor Configuration with Preprocessors



the communications equipment under the control of the preprocessors. This configuration is included to show the trend of distributed processing.

a. Operation

The preprocessors perform the polling, data collection, error checking, and conversion to engineering units. Depending on the Vendor's implementation, the preprocessors might additionally perform limit checking and some man/machine interface functions. As shown, failover is accomplished by simultaneous switching of both the CPU's and the associated preprocessors. Preprocessors are dedicated to a single CPU and are not capable of operation with the 'opposite' CPU. This configuration is shown in a general case, actual implementation is highly Vendor dependent and may differ in the allocation of functions and failure capability.

(1) Advantages

(a) Can fully meet virtually any borrower's requirements while maintaining a better distribution of computational load to allow easier system growth.

(b) High responsiveness to operator requests is provided.

(c) Shares the advantages of Configuration 2.

(2) Disadvantages

(a) Purchase costs are higher than in basic dual CPU system, Configuration 2.

(b) Maintenance costs are higher due to increased system complexity.

(c) Software changes will probably have effects in both sets of computers.

(d) Preprocessor computer program generation and testing requires either additional peripheral devices or an emulator program in the main CPU.

(e) Programmers may be required to learn either high order or two languages and operating systems if different CPU's are used for each function.

D. <u>Cost Summary</u>

Tables V-1 through V-8 provide a means of budgeting for discrete elements within an energy control system structure but by themselves they do not provide a convenient means of assessing the total system costs. Table V-9 provides a cost summary for a dual CPU configuration similar to that shown in Figure V-2, the most typical system used in REA energy control centers. Rather than provide a single average for each cost element, a low average and a high average for each of the various costs shown is provided. The RTU costs are excluded from the total base system costs since they are unique in both type and quantity for each system undertaken. However, a space is provided at the end of the table as a reminder for their inclusion in order to establish the total system price.

The specified functions to be performed by the energy control system and included in the applications software are:

- o Data acquisition and monitoring
- o Supervisory control
- o Load management
- o Automatic generation control
- o Interchange scheduling
- o Information storage and retrieval

Costs for testing are for a 1,000 hour availability test.

Spare parts costs are over a minimum ten year life of the system.

TABLE V-1

COMMON HARDWARE COSTS

DISPATCHERS CONSOLE:	$59,000
Limited Graphic Color CRT (2)	
CRT Keyboard (2)	
Function Pushbutton Panel (2)	
Console Furniture	
Controller (2)	
TRAINING CONSOLE:	$50,000
Limited Graphic Color CRT, with Keyboard	
Function Pushbutton Panel	
Console Furniture	
Controller	
PRINTERS:	$42,000
Programmer/Engineers Typer-KSRs (2)	
Loggers (2)	
Line Printer	
Controllers	
MAGNETIC TAPE CONTROLLER AND DRIVE:	$35,000
RECORDING AND INDICATING DEVICES:	$44,000
Trend Recorders (10)	
Numeric Indicators (10)	
RTU COMMUNICATIONS INTERFACE:	$75,000
Communication Controller	
Data Set/Controllers	
Line Switching Unit	
Maintenance Panel	
LOCAL INPUT/OUTPUT:	$30,000
Local RTU	
Trend Recorder Analog Outputs	
Numeric Indicator Digital Outputs	
Analog Outputs	
Digital Outputs	
KWH Command Inputs	
Frequency Tranducer	
INTERCONNECT TRANSMISSION EQUIPMENT:	$10,000
KWH Transmitters (6)	
Tone Equipment	
Interconnect RTU	

TABLE V-2

COMMON SOFTWARE COSTS

BASIC SOFTWARE:	$40,000
Operating System	
• Resource Management	
• Restart	
• Device Management	
System Software	
• Output Message Subsystem	
• Scheduler	
• CRT I/O Subsystem	
Malfunction Diagnostics	
Console Processor	
Mapboard Driver	
Trending Software	
DATA BASE, CRT AND LOG FORMAT GENERATION:	$50,000
DATA COLLECTION:	$15,000
RTU Interface	
Local I/O	
APPLICATION SOFTWARE:	$30,000 to $50,000 per program
Automatic Generation Control	
Economic Dispatch Calculation	
Interchange Scheduling	
Supervisory Control	
Data Processing	
Data Logging	
Load Shedding and Restoration	
System Peak Analysis	
Energy Accounting	
Disturbance Analysis	
Storage and Retrieval	
COMMUNICATION SOFTWARE:	$18,000
Data Exchange with Interconnect Utilities	
DIAGNOSTIC SOFTWARE:	$15,000
On-line Version, Each Peripheral	
Off-line Version, Each Peripheral and CPU	
BACKGROUND PROCESSORS:	$40,000
Fortran Compiler	
Assembler	
Source Editor	
Utility Functions	
Test and Integration	
Auxiliary Memory Management	
Data Base Generator	
CRT Picture Compiler	

TABLE V-3

REMOTE TERMINAL UNIT COSTS

Type	Price Range
Generation RTUs	$10,000 - $19,000/Unit
Bulk Delivery Substation RTUs	$ 8,000 - $18,000/Unit
Bulk Delivery Line Tap RTUs	$ 3,600 - $ 5,200/Unit
Meter Point RTUs	$ 4,000 - $10,000/Unit
RTU Installation Material	$300/Unit
RTU Installation Time-Average	3 Manweeks/Unit

TABLE V-4

OPTIONAL COSTS

ECONOMIC DISPATCH CALCULATION: Optimization of Total Generation Costs Unit Base Points and Participation Factors	$20,000
LOAD SHEDDING AND RESTORATION: Recording of Outage Timing Warning Dispatcher when Time to Rotate Outage	$25,000
AUTOMATIC TELEMETRY OVERRIDE: Substitution of Data from Historial File for Failed Metering Point Telemetry.	$20,000
CRT HARDCOPY: Special Logger Characters Software	$ 8,000
DYNAMIC MAPBOARD: Mapboard with Electro-magnetic Indicators Computer Interface Software	$100,000
SINGLE CRT CONSOLE: Limited Graphic Color CRT CRT Keyboard Function Pushbutton Panel Console Furniture Controllers	$40,000
REDUNDANT KEYBOARD/FUNCTION PANEL: CRT Keyboard Function Pushbutton Panel Switching Matrix	$20,000

TABLE V-5

COST OF ENGINEERING AND IMPLEMENTATION SERVICES

Item	Description	Cost
1	Preparation of system study specification bid evaluation and vendor selection	$ 80,000
2	Software monitoring, programming and training.	$100,000
3	Hardware monitoring, power system engineering and training.	$ 75,000
4	System Dispatcher support and training.	$ 30,000
5	Installation (RTU's excluded).	$ 45,000
6	Factory and field acceptance testing.	$ 60,000
7	Training.	$ 50,000
8	Documentation.	$ 40,000
9	Freight and insurance.	$8,000 to $16,000
10	Engineering services.	$100,000
11	Project Management.	$ 60,000
12	General & Administrative	$ 40,000

TABLE V-6

CONFIGURATION #1 - MASTER STATION COSTS

CPU (16 - BIT) WITH 256 KB MAIN MEMORY: Power Fail Safe Memory Protect/Management Boot-Strap Loader Interrupt Control/16 Interrupts External Input/Output Channel Processor (IOP) Parity Trap	$100,000
AUXILIARY MEMORY	$ 60,000
SPARE PARTS AND TEST EQUIPMENT:	$ 65,000
COMMON HARDWARE FROM TABLE V-1	$345,000
COMMON SOFTWARE FROM TABLE V-2	$328,000
Software Subtotal:	$328,000
Hardware Subtotal:	$570,000
Total Configuration 1 Costs ($\pm$10%):	$898,000

TABLE V-7

CONFIGURATION #2 - MASTER STATION COSTS

CPU (16 - BIT) WITH 256 KB MAIN MEMORY (2):	$200,000
Power Fail Safe	
Memory Protect/Management	
Boot-Strap Loader	
Interrupt Control/16 Interrupts	
External Input/Output Channel Processor (IOP)	
Parity Trap	
AUXILIARY MEMORY - (2):	$120,000
CPU TO CPU LINK:	$ 8,000
PROGRAMMERS TYPER (KSR) FOR SECOND CPU:	$ 7,000
PERIPHERAL DEVICE ACCESS:	$ 45,000
Redundant Controllers	
Logger	
Line Printer	
Console	
Communications	
Magnetic Tape	
Dual Porting and/or Peripheral Switches	
SPARE PARTS AND TEST EQUIPMENT:	$ 70,000
COMMON HARDWARE FROM TABLE V-1	$345,000
SOFTWARE FOR REDUNDANCY:	$ 25,000
Failover Programs	
Intercomputer Communications	
Auxiliary Memory Snapshot	
COMMON SOFTWARE FROM TABLE V-2	$328,000
Software Subtotal	$353,000
Hardware Subtotal	$795,000
Total Configuration 2 Cost (±10%)	$1,148,000

TABLE V-8

CONFIGURATION #3 - MASTER STATION COSTS

CPU (16 - BIT) WITH 256 KB MAIN MEMORY (2):	$200,000
Power Fail Safe	
Memory Protect/Management	
Boot-Strap Loader	
Interrupt Control/16 Interrupts	
External Input/Output Channel Processor (IOP)	
Parity Trap	
AUXILIARY MEMORY - (2):	$120,000
CPU TO CPU LINK:	$ 8,000
PROGRAMMERS TYPERS (KSR) FOR SECOND CPU & PREPROCESSORS (3):	$ 21,000
PERIPHERAL DEVICE ACCESS:	$ 45,000
Redundant Controllers	
Logger	
Line Printer	
Console	
Communication	
Magnetic Tape	
Dual Porting and/or Peripheral Switches	
PREPROCESSORS - CPU (16 - BIT) WITH 32 KB MAIN MEMORY (2):	$ 55,000
SPARE PARTS AND TEST EQUIPMENT:	$ 80,000
COMMON HARDWARE FROM TABLE V-1:	$345,000
SOFTWARE FOR REDUNDANCY:	$ 25,000
Failover Programs	
Intercomputer Communications	
Auxiliary Memory Snapshot	
SOFTWARE FOR PREPROSSING:	$ 60,000
Basic Software - Operating System	
Data Base Generation	
Intercomputer Communication	
Diagnostics	
COMMON SOFTWARE FROM TABLE V-2:	$328,000
Software Subtotal	$413,000
Hardware Subtotal	$874,000
Total Configuration 3 Cost (±10%):	$1,287,000

TABLE V-9

COST SUMMARY
DUAL CPU CONFIGURATION - 256 KB MAIN MEMORY

Item	Low Average	High Average
CPU's	$ 275,000	$ 500,000
Auxiliary Memory	50,000	85,000
Local I/O	20,000	40,000
Communications Interface	55,000	100,000
Spare Parts	150,000	200,000
Peripherals		
Magnetic Tape	15,000	19,000
Line Printer	15,000	17,000
Loggers	10,000	12,000
Miscellaneous	18,000	25,000
Man/Machine Interface		
Display Generators	30,000	38,000
Monitors	10,000	16,000
Keyboards	5,000	7,000
Function Panels	2,000	5,000
Consoles	7,000	12,000
Recorders	40,000	45,000
Indicators	6,000	12,000
Basic Software	35,000	80,000
Application Software	250,000	375,000
Training	35,000	60,000
Installation (RTU's excluded)	45,000	65,000
Testing	29,000	45,000
Insurance & Freight	8,000	16,000
Documentation	30,000	60,000
Engineering	190,000	300,000
Total Base System Price	$1,330,000	$2,134,000
RTU's - Use Table V-3		
Generation		
Bulk delivery line tap		
Bulk delivery substation		
Meter point		
Total System Price		

APPENDIX A

APPLICATION PROGRAMS

A. General

The power application programs described in this section fall into several functional categories. These categories are real time dispatch, dispatch studies, utilities, advanced dispatch functions, off-line dispatch of scheduling, and system security aids. The illustration on the following page shows this categorization of application functions.

The real time dispatch functions are those which have traditionally been a part of electrical power dispatch offices: automatic generation control, economic dispatch, and interchange scheduling. The dispatch studies include economy transaction evaluation and production costing, and the advanced dispatch functions include the use of penalty factors and distribution factors from a real time load flow, for the economic dispatch and study functions.

The system utilities include a variety of data recording, analysis, and monitoring functions - data logging, overload monitoring, and reserve monitoring.

The scheduling and security analysis programs include some of the more advanced software available in the industry today. The scheduling functions include an advanced unit commitment program. The security analysis programs include A.C. contingency analysis programs, in both real time and study versions, a dispatcher or operator oriented load flow, and a state estimation.

The implementation of the entire set of these applications programs would result in one of the more sophisticated and functionally powerful dispatch offices in the world today. These applications programs have been designed to conveniently bring the dispatcher the benefit of state-of-the art analytical tools for secure and economic operation.

A description of the standard AGC system is presented along with a brief description of each of the advanced application functions. The descriptions are not intended as a complete functional specification but merely serve to identify the scope of software functions.

B. Application Programs

1. Digital Automatic Generation Control (AGC)

This section describes an Automatic Generation Control System (AGC), providing general information on the AGC

POWER APPLICATION PROGRAMS

REAL-TIME DISPATCH

Automatic Generation Control
Economic Dispatch
Interchange Scheduling

DISPATCH STUDIES

Study Economic Dispatch
Economy Transaction Evaluation
Production Costing

ADVANCED DISPATCH

Real-Time Penalty Factors
Load Forecast
Real-Time Load Flow

SCHEDULING

Unit Commitment

SYSTEM UNIT UTILITIES

Data Logging
Overload Monitoring
Reserve Monitoring
Information Storage and Retrieval
Historical Data Storage

SECURITY ANALYSIS

Contingency Analysis
State Estimation
Dispatcher Power Flow

system as a whole, and providing detailed descriptions of the three software subsystems:

- The Load Frequency Control Subsystem
- The Interchange Scheduling Subsystem
- The Economic Dispatch Subsystem

The displays, printouts, alarms, man-machine interface, and operating modes of the AGC system are also described in this section.

The basic purpose of the AGC system is to assign automatically controlled generation in such a way that interconnected system load is being supplied. The generation assignment is made such that the desired interchange schedule is maintained and the generation is done as economically as the interconnected system conditions permit.

a. <u>An Overview of the AGC System</u>

At frequent intervals, the Energy Management System scans the area for the following quantities:

- Actual Tie Line Power Flows
- Actual Area Frequency Deviation
- Actual Output Power of each Generator Unit

The tie line power flows and the frequency deviation are used by the LFC subsystem of the AGC system in the calculation of Area Control Error (ACE). ACE is measured in units of power such as megawatts. It represents the total error between the interchange being demanded and being supplied, as well as a megawatt adjustment for the frequency error.

It is the responsibility of each area in an interconnected system to minimize ACE at all times. When the value of ACE is not zero, it indicates that an area is either not maintaining the desired scheduled interchange, that it is not doing its share in the control of interconnection system frequency, or both.

Once ACE has been determined, the LFC subsystem must distribute this error in the power needed among each of the controllable generators. Once the distribution is made, the power increment from each controllable generator is converted into the required raise or lower pulses.

In addition to the control of generator output power being done by the LFC subsystem, a means must be provided for altering the scheduled interchange power. The interchange scheduling subsystem is used for entering new scheduled interchange data, computing the net interchange power, and for transmitting the schedule change data to the LFC subsystem.

b. Load Frequency Control Subsystem

The Load Frequency Control (LFC) subsystem contains the following tasks which are needed to carry out its portion of the Automatic Generation Control functions:

- Area Control Error Task
- Power Allocation Task
- Generator Pulser Task

There are a number of restrictions placed on the execution intervals of the tasks in the LFC subsystems. First, for good control action, the tasks should not be executed less frequently than once every ten seconds. Next, when considering CPU loading, the most frequent execution of the LFC subsystem is: the Area Control Error Task once every two seconds; the Power Allocation and Generator Pulser Tasks at an integer multiple of the ACE Task Interval.

A further restriction is placed on the Power Allocation and Generator Pulser Task, they must always have the same execution interval. Finally, the execution interval of the latter two tasks must be an integer multiple of the execution interval of the Area Control Error Task. These last two LFC software modules should cause no practical limitation for AGC system users.

The Area Control Error Task smoothes the scanned area quantities and calculates the smoothed value of the Area Control Error. On completion of this task, the Power Allocation Task may be called into execution, depending on the ratio of the execution intervals.

The Power Allocation Task allocates the smoothed Area Control Error among the controlled generators using the current base points and percent participation factors. The use of these quantities during the allocation allows economy to be considered. This task then converts the power allocated to each generator into raise or lower

pulses for each generator. On completion, this task calls the Generator Pulser Task. This latter task uses SEMS to transmit the raise or lower pulses to the controlled generators.

AGC uses the standard man-machine interface and control ability provided by the SCADA system, with the addition of the generator unit controllers.

Frequency bias and scheduled frequency for time corrections are operator enterable via CRT. Scheduled net interchange is calculated from data obtained from the interchange Scheduling Program.

The Area Control Error is capable of being controlled with a minimum amount of control action (i.e., short term cyclic loading of generators is suppressed as much as possible without excessive loss of control effectiveness). This is accomplished by digital smoothing of frequency deviation, actual tie line flow value, and actual generator megawatt outputs. In addition, the ACE value is digitally smoothed again with a double level digital filter. By proper choice of the above set of smoothing constants, the high frequency component in the ACE errors can be effectively filtered. The resultant smoothed value of ACE represents only the longer term error on the power system.

When the ACE consists entirely of noise (non-controllable components), the regulating units are controlled at their economic base points.

Control action shall be allocated to the units on control according to their:

- Control mode
- Participation factors (Economic and Regulation)
- Deviation from economic level

Control action shall be constrained by unit operating limits, response rate limits, and anticipated unit response to previously taken control action.

Emergency assist action is provided using the ACE level mode. Normal EDC, Permissive EDC, and Assist actions are used for the descriptions of these modes in the section describing AGC modes and generator modes (all

changes in LFC subsystem modes result in alarms to the AGC operator).

The LFC subsystem includes an automatic inadvertent interchange payback capability. The operator is able to monitor or override this feature through the CRT.

AGC controls to generators are suspended, but ACE computations shall continue when:

- AGC is in flat frequency control, or tie line bias control, and the system frequency telemetering fails.

- AGC is in flat tie line control, or tie line bias control and:

  - Tie line MW telemetering fails, or
  - The actual net interchange deviates from the scheduled net interchange by greater than a preset limit.

The operator is able to reset control when the problem has been corrected.

The following conditions cause the LFC subsystem to suspend sending control pulses:

- Excessively large smoothed ACE values.

- Excessively large frequency deviation values.

To observe the long term behavior of the LFC subsystem, the following parameters are provided on the CRT:

- The hourly mean value of ACE.

- The hourly standard deviation of ACE.

- The hourly maximum value of ACE.

In addition, the hourly number of control pulses that are sent is displayed.

c. Interchange Scheduling Subsystem

The Interchange Scheduling Subsystem translates generation schedules from the static operator input format to the

dynamic input required by the load frequency control program.

The Interchange Scheduling Subsystem maintains the files of ongoing and future power transactions with different companies. It processes these transactions at the appropriate time, and provides the net schedule and the ramp rate as an input to the load frequency control program.

The following functions and capabilities are included:

- A separate page of schedules per facility
- Allows operator to enter, delete or modify any schedule
- Capability to enter schedules one month in advance
- Each schedule to have:

  Start time
  Stop time
  Ramp
  Duration of ramp
  Net schedule
  Type of transaction
  Local price
  Foreign price

- Transactions with a company to be displayed in chronological order by start time
- Validate operator entered data.
- Notify operator five minutes prior to start of schedule
- Log all changed schedules
- Calculate net schedule and net ramp and pass to load frequency program
- Delete completed schedules

The Interchange Scheduling functions are performed by

using two separate tasks. The generation schedule files are updated and maintained by the task schedule file (SCHFIL). SCHFIL receives new or changed schedules, performs validation of operator entered data, does logging, and sorts the schedule files chronologically.

Generation schedules are grouped by the company participating in the transaction. There can be one or more pages per company. The operator can select one or more schedules in a page for one of two functions, either Entry or Deletion. Previously entered schedules which are to be modified are processed via the entry function.

Schedules (including blank schedules) can be selected for processing by entering an asterisk in the Select Field for that schedule.

To delete schedules, the operator selects the schedules he wants to delete and then executes the delete function.

To enter or modify schedules, the operator writes or overwrites on Selected Schedules and then executes the Enter function. The schedules will appear packed and sorted within the company, in chronological order by start time.

Any schedules which have an invalid operator entry will be rejected and lost, the operator will be notified of this via a message on the top system line.

In-place entries on the screen for schedules which have not been Selected, will be rejected and lost. The previous data will reappear on the screen. No message will be generated.

A duplicate copy of the schedule file is maintained to preserve the integrity of the data base against operator entry error, and to distinguish modified schedules. One copy of the file is used for operator display and entry. The other copy is maintained and updated with valid operator entries by SCHFIL.

Both copies will have the FORTRAN Interface Common structure and will reside on disk.

NXTSCH accesses the AGC common to put in the values of the net schedule and ramp rate.

d. Economic Dispatch Control Subsystem

The Economic Dispatch Control (EDC) Subsystem contains the following tasks:

- Economic Dispatch Control Task
- Spinning Reserve Task
- Incremental Cost Curve Calculator Task

Much more latitude is permitted in the selection of the execution intervals of the EDC subsystem. The Economic Dispatch Control Task and the Spinning Reserve Task need not use the same execution interval. These intervals may be as frequent as once every two minutes. However, no upper limit on execution interval exists. Under certain circumstances, a borrower may indeed choose to have no EDC calculations being performed. If this method of operation is selected, the AGC operator must manually enter the base points and percent participation factors.

The Economic Dispatch Control Task is the first task of the EDC subsystem to be executed at each execution interval. This task determines the most economical distribution of power among the controllable generators that is needed to supply the current power system load. In addition, the generator power output is checked by the Spinning Reserve Task to assure that the spinning reserve requirements are met. The Incremental Cost Calculation Task is not scheduled for repetitive execution. The AGC operator will execute this task each time the generator fuel costs or the generator incremental heat rate curves are changed. This task will be executed on the background CPU. The task is used to calculate the incremental cost curves from generator fuel cost and generator incremental heat rate curve data stored on the disk. It need only be called each time this stored data gets updated.

Although the EDC subsystem is scheduled for repeated execution, the AGC operator may wish to cause a special execution at some given time. This can be accomplished using the CRT displays for AGC.

The Economic Dispatch Control Subsystem allocates generation among controllable generators in such a way as to minimize system production cost to meet the system load. Each time the EDC executes, it determines the economic

distribution of the load among the controlled generators. The requirement for each generator is referred to as that generator's base point and each generator is given a percent participation factor which is derived from its invremental cost curve.

There are two modes of EDC operation:

- EDC on
- EDC off

The Economic Dispatch Program executes periodically, when a unit is placed on or off automatic control, or when the deviation from the previous generator base points exceeds preset limits. The program calculates desired generation levels and participation factors for regulated units, unit and system fuel costs, and transmission losses. The system transmission losses are determined with the B matrix and B_o vector using the standard quadratic formula for losses.

The EDC has the capability of containing three unique incremental heat rate curves for each generating unit:

- Fuel Type 1
- Fuel Type 2
- Fuel Type 3

Any one of three different incremental heat rate tables can be utilized for each generator. Modification of fuel costs and fuel type is done using the CRT. Modification of the heat rate tables can also be done through the CRT by using the SEMS Editor. This would typically require a programmer's skills.

The operator shall have the capability of entering a system regulating margin (time limited reserve) requirement that is to be available during emergency assist. This is done using the Spinning Reserve Task.

The EDC calculation executes as often as once every two minutes. It uses the same unit operating limits that the LFC subsystem uses.

- Unit operating low limit

- Unit dispatcher's high limit

- Unit operating high limit

As long as all units are below the dispatcher's high limit, these limits are used. When all units reach the dispatcher's high limit, both LFC and EDC subsystems change to the operating high limit. Alarms are given when this occurs.

The dispatcher's high limits allow the operator to specify a unit spinning reserve for each generator which LFC must respect until system conditions require that reserve be used to meet excessively high system loads.

Pertinent economic dispatch calculated values, such as system incremental cost, unit base points, and unit participation factors, are displayed via CRT to the operator.

e. <u>Information Flow Description</u>

The information needed from the power system, such as tie line power, frequency deviation, and generator power, is obtained using the Energy Management System (SEMS). Other information may be input by the AGC operator using the CRT's. This information is deposited in the appropriate AGC data files.

Data files organization is important to the information flow and efficient operation of the AGC system. Each subsystem may have one or more data files for its own use. Each of these data files are part of the general data base.

Communication of the data among the AGC subsystems is handled by the AGC data file. By organizing the data files in this manner, a significant reduction is made in the maximum size of core needed for the individual subsystems during execution.

An important element in the information flow is the AGC operator. By observing the displays, he can monitor the status of the power system. As unusual conditions arise, the AGC operator can interact with the AGC system through the CRT's. The CRT's can be used to automatically update the appropriate data files when data changes are needed.

f. AGC CRT Displays

Table A-1 lists the eight CRT possible displays that are used with a typical AGC system. The figure lists the number of pages for each CRT for a typical AGC installation. For an application with a small number of generators, some of the multiple page displays may be combined. For an application with a large number of generators, each page displaying generator data may require more than one CRT display page. Each of these displays will be discussed briefly.

Table A-1

DISPLAY	NUMBER OF PAGES
AGC Status and Control Summary	1
AGC Alarm and Acknowledge Page	1
Unit Generation and Summary	2
Tie Line Power Flow Setup	1
Interchange Transactions Setup	AR
AGC Data Setup	3
Economic Dispatch Control Setup	1
Spinning Reserve Setup	1

(1) AGC Status and Control Summary

The AGC Status and Control Summary Display provides information of all the key AGC quantities. The operator can see at a glance what the area status is, and which of the control modes of AGC operation are currently being used.

Of primary interest to the AGC operator is the current ACE value, the area load, the on-line capacity, and the area spinning reserve.

The AGC operator can use this page to observe the system status, and can modify the AGC system opera-

tion by selecting other states for the various modes.

(2) AGC Alarm Acknowledge Page

This page is used by the AGC operator to acknowledge the alarms for the subsystem. The acknowledge point for each alarm is at the far left of each line. The alarm state and alarm description identify the alarm that is to be acknowledged. Any alarms awaiting acknowledgement will be shown flashing on and off.

The alarm description precedes the repeated alarm acknowledge points and points for each generator in the system.

(3) Unit Generation Summary

The unit generation summary uses two pages, both organized in the same way. Each row is devoted to a separate generator unit. Each column is used to display and/or enter the data for each generator.

The AGC operator uses the page to enter generator limits, base points, and present participation factor.

(4) This display is used by the AGC to observe and update the data used for each tie line. Each row represents a separate tie line. There are three types. First, the tie lines which are normally being scanned; this display would show the power flowing on that tie line under the telemetered tie line flow column. Next, there are tie lines which ordinarily are being scanned, but are currently not due to equipment failure. Here, the AGC operator enters an estimated value for this line's power flow into the substituted tie line flow column. Finally, the untelemetered tie line flow column shows the tie lines which are never scanned, because no telemetering equipment exists. The operator must enter an estimated value for the actual flow on each of these types of tie lines.

At the bottom of this display are the total power flows for the various types of tie lines.

(5) Interchange Scheduling Setup

The AGC operator uses this display to enter the desired interchange schedules for a given company. Each entry occupies one row on the display, allowing 30 entries on a single page. There is one month time constraint on the future start and stop times for entries. There will be one display of this type for each company with which interchanges are scheduled.

(6) AGC Data Setup

This three page display is used to enter data to the AGC system. On page 1 are such items as alarm limits, frequency bias, number of generators, and number of tie lines.

Most of the items on page 2 and 3 are entered when the system is first started up,and rarely changed again. Page 2 is used to enter the generator control constants for the low end at the generator operating range. Page 3 is used to enter the control constants for the high end.

(7) Economic Dispatch Control Setup

This CRT may be used for entering new base points and percent participation factors.

(8) Spinning Reserve Setup

This display is used by the AGC operator to set up the data for the Spinning Reserve Task. Data needed for the spinning reserve calculation is entered using this CRT. The spinning reserve results for each generator, as well as totals, are displayed on this page. The spinning reserve alarm is also acknowledged on this page.

g. AGC Modes of Operation

There are a number of modes of operation in the AGC system. Most of the modes are used to modify or indicate the status of the LFC subsystem. However, several are used to indicate the status of the Interchange Scheduling Subsystem.

The following modes are used:

- LFC Control Mode
- ACE Calculation Mode
- Schedule Change Mode
- Time Correction Mode
- LFC Data Base Mode
- Generator Control Mode
- Tie Line Scan Status Mode
- Economic Dispatch Mode
- Penalty Factor Mode
- Spinning Reserve Mode

The most important mode in the AGC system is the LFC control mode. It has the following states:

- LFC On
- LFC Off
- Open Loop

In the Open Loop State, all of the LFC functions are performed except the actual pulse transmission to the generators. This mode is used to verify the AGC system actions as each new generator is put under AGC control.

In the LFC Off State, LFC and its functions, as well as interchange scheduling functions, are inoperative. These latter subsystems require LFC to carry out their respective functions.

The LFC On State is the normal state used. When the LFC On State is selected, LFC can be used to automatically perform its various functions. The EDC and Interchange Scheduling Subsystems can also accomplish their function.

The next most important mode is the ACE calculation mode. It has the following states:

- Tie Line Bias
- Flat Frequency
- Flat Tie Line

Although the Flat Frequency and Flat Tie Line states may be selected, the state most frequently used for this mode is the Tie Line Bias method of ACE calculation.

The ACE level mode has the following states:

- Normal EDC

- Permissive EDC
- Assist

Each of these states is entered automatically by the LFC Subsystem. An alarm indicating the status change is given and must be acknowledged by the AGC operator. Although the AGC operator cannot select any of the states in the ACE level mode, he can influence their selection by using CRT to enter the ACE error level that must be achieved before a state transition is made. The states are listed above, in increasing levels of ACE error.

In the Normal EDC State, all generators are moved by the LFC Subsystem, to the most economic operating point computed by the EDC Subsystem. In Permissibe EDC, only those generators whose change in output helps reduce the ACE level, are moved to the most economical operating point. In the Assist State, the LFC System attempts to correct ACE error while completely disregarding the EDC operating point data.

The Schedule Change Mode is used to indicate whether a schedule change is in progress. Three states are possible:

- Schedule Change Completed
- Schedule Change in Progress
- Schedule Change Desired

The Schedule Change Completed State is most frequently used. When a schedule change is needed, the Schedule Change Desired State is entered. The state is maintained until LFC starts making the schedule change. Then the Schedule Change in Progress State is entered. Upon completion of the schedule change, the Schedule Change Completed State is re-entered.

The Time Correction Status is used to indicate whether the time correction relationships are in use. These states are possible:

- Time Correction Completed
- Time Correction in Progress
- Time Correction Desired

Most of the time, the LFC Subsystem is operated in the Time Correction Completed State. When a time correction is required, the AGC operator uses the CRT to enter the

desired frequency offset and the start and stop times for the correction. When the LFC starts making the time correction, the Time Correction in Progress State is entered. When the time correction is completed, the Time Correction Completed State is entered and displayed.

The Economic Dispatch Mode is used to indicate which type of economic dispatch is wanted. Three states are possible:

- EDC On
- EDC Off
- Immediate EDC Execution

The most frequently used state is the EDC On State. Using this state the EDC Subsystem automatically calculates the base point and percent participation factor information. If the EDC Off State is selected, this data must be entered manually using the CRT. The Immediate EDC Execution State is used by the AGC operator to get the EDC Subsystem executing as soon as possible.

The Penalty Factor Mode is used to select the type of penalty factor calculation that is desired. Three choices are possible:

- Unity Penalty Factor
- Constant Penalty Factor
- Calculated Penalty Factor

The Spinning Reserve Mode is usually specially designed for each customer.

The LFC Data Base Mode has the following three states:

- Normal
- Hot Start
- Cold Start

To start up the AGC System, the Cold Start State is selected. In this case the working AGC Data Files are created from stored values on the disk. In normal operation of the AGC System, the Normal State is selected. If LFC is turned off for a short period of time, the operator may choose the Hot Start State. In this state, the LFC Subsystem creates an updated set of smoothed scanned values and then makes a transition to the Normal State.

In addition to the nine modes used for control of the AGC System, two additional modes are used in conjunction with the generators and tie lines. The Generator Control Mode indicates the state of each of the LFC controllable generators in the area. It has five states:

- Off
- Manual
- LFC Only
- EDC Only
- LFC and EDC

In the Off State, the generator output power is not automatically included in the LFC calculations. In the Manual State, the generator output is automatically included in the LFC calculations, but no raise or lower pulses are calculated or transmitted to the generator. The LFC Only and the EDC Only States are used when a generator is used in that restricted mode of operation respectively. In the LFC and EDC State, the generator output and the EDC information is automatically included in the LFC calculations and the appropriate raise or lower pulses are calculated and transmitted. There is no most likely state for a generator to be in. All day long the generator states will be changed to one of the five permitted, in order to adjust generation to changing loads.

When the EDC Subsystem is in the EDC Off State, the AGC Operator must enter base points and percent participation factors for each of the generating units. It is when EDC Off is used that the Base Load Regulation and Base Loaded Generator Unit States are achieved.

The Tie Line Scan Status is used to indicate the state of each of the tie lines in the area. Two states are possible:

- On
- Off

In the On State, the tie line power is automatically scanned and smoothed by the LFC Subsystem. This is the normal state for a tie line to be in. In the Off State, usually selected when there is a channel communication failure, the tie line power is no longer automatically scanned. If the tie line is actually carrying power, the AGC Operator must add this tie line power value to

the unmetered tie line power, and deposit the result in the LFC Data File using SEMS.

h. General Subsystem Information

(1) Principal Inputs and Outputs

Of the variety of information needed by the AGC System, there are a number of principal input and output quantities. Input quantities include:

- Tie Line Power
- Generator Unit Power
- Frequency Deviation
- Schedule Change Information

The principal outputs include:

- Area Control Error (for control and display)
- Generator Raise, or
- Lower Pulses (for control and display)

(2) AGC Alarms

All of the alarms given by the AGC System are of the information type. That is, they are given when a specific condition is detected during the AGC Operation. However, two of the LFC alarms are for such extreme conditions that they turn off the LFC Subsystem.

In most instances, it is up to the AGC Operator to interpret the alarm and its cause, and to take appropriate remedial action. The AGC Operator must also acknowledge each of the AGC alarms.

(3) Internal Interfacing

The core resident AGC Data File serves as the main communication mechanism among the subsystems in the AGC System. Both the EDC and Interchange Scheduling Subsystems utilize data in the AGC Data File. The results of the calculations of these two subsystems are communicated to the LFC Subsystem through the AGC Data File.

2. Economic Dispatch Calculation (EDC) Monitor

The EDC Monitor Program is a special purpose program of the

generalized AGC/EDC Solution routine which forms the basis of the Automatic Dispatch EDC. Used as a dispatcher aid, it monitors real-time system load conditions and provides recommendations to the dispatcher, via system displays, for loading of units which are not automatically dispatched. These units are normally fixed-base loaded, or not equipped for automatic control. The dispatcher is provided with full control over which units are economically monitored. In this way, units that are constrained to specified levels of loading are not included in the dispatch, and will not influence the loading of monitored units.

In use, the dispatcher can periodically review the relative loading of all units available to him, and institute manual rebalancing, resulting in better economic operation. This program can enhance the effectiveness of automatic economic dispatching through the AGC/EDC Programs, by providing data for the dispatcher to enable him to economically dispatch the off-control and fixed-base generators.

The EDC Monitor Program begins by determining which generators are to be included in the Economic Dispatch Solution, for the determination of desired generations. The dispatcher, through CRT entries, can include or exclude generators from the EDC Monitor Solution. All other generators are dispatched to the values they are to attain after any of the off-control or fixed-base generators are directed to their new base points

The EDC Solution Routine is then executed to determine the Desired Generation values of the generators included in the EDC Monitor Program. The EDC Solution Routine is solved for the case of Total Gross Generation Required, being equal to the current Actual System Total Gross Generation. All other input data, such as System Regulating Margin Required, Generator Limits, Tie Line Flows, etc., is taken from the current real-time system data base.

The final processing associated with the EDC Monitor Program is to calculate system production costs based on the current actual generations. An alarm message to the dispatcher is initiated if a significant improvement in current production cost is possible.

The EDC Monitor Program results are stored into the system data base for subsequent use in CRT Displays.

3. Economics Dispatch Calculations (EDC) Study

The EDC Study Program is a special-purpose embodiment of the

generalized EDC Solution Routine for performing special-case economic studies. Unlike the EDC Monitor Program, which uses real-time data in the monitor mode, the EDC Study Program operates with user specified data under the direction of the user.

The EDC Study Program can be utilized in some systems as an Operations Planning Aid. Members of the Operations Planning Staff might use the program in conjunction with their responsibilities for developing plans for short-term future operations. The power dispatcher might utilize the EDC Study Program to evaluate an immediate proposed change of generator operating conditions or to evaluate the performance of a newly installed generator.

In addition to the operational uses of the EDC Study Program, the engineering staff can utilize the program to evaluate the effect of system data modifications (data compiler entries) on the EDC Program Solutions. For example, the data used to describe a new system generator could be added to the computer system and evaluated by use of the EDC Study Program to ensure the validity of the generator data. In addition, new B matrix loss coefficients can also be evaluated before use in the real-time system.

The EDC Study Program is manually initiated and the user (dispatcher or operator) is allowed full control to either accept or modify the data inputs (System Load, System Interchange, Regulating Margin Required, Generator Status, Generator Limits, etc.).

The Study Data Base Initialization Logic shares the initialization processing characteristics of other study programs. The study data base is initialized to a judicious combination of current (real time) and forecast (Load Forecast, Interchange Schedule) conditions, in a manner which provides all data required for the study solution, with the minimum necessary amount of user entries.

The EDC Study Program results are available to the user via the CRT Displays, or optionally, the user may choose to direct the study program results to the system printer. The data results are available until such time as the study program is terminated.

4. Transaction Management Package

The Transaction Management Package consists of a design

coordinated set of five programs which support all functions associated with the evaluation, scheduling, and accounting of interchange schedules. They are interfaced with standard data acquisition, data base, and man-machine software subsystems. Programs execute periodically or on demand by the dispatcher. All operator interface with these programs is through appropriately defined CRT Displays. The focal point of these programs is the Transaction Inventory Files. These data files are maintained in bulk memory, and contain all data pertinent to past, pending, and future Scheduled Interchange Transactions.

Interchange schedules are entered by the dispatcher through the Interchange Transaction Scheduler Program. This program maintains an inventory of all transactions until they are canceled or completed, and processed. It also determines the scheduled net interchange, and implements schedule changes through the Automatic Generation Control Program.

The actual production costs associated with each ongoing transaction are computed periodically by the Transaction Reconstruction Monitor Program. This program calculates the average cost of each active transaction using data from the EDC Solution Routine. The data resulting from these calculations is stored in the cost reconstruction data files which are part of the Transaction Inventory.

Periodically, each hour, the Transaction Accounting Monitor Program processes the data associated with transactions completed during the last hour. This includes actual kWh data acquired by the data acquisition function. This data is combined with other pertinent data stored for each transaction in the Transaction Inventory Files. This processed data is stored on a daily basis in the Completed Transaction Files. This information can be printed in summary form for each day's operation, for use in billing operations. In addition to this billing data, historical records are also constructed in the form of daily files of hourly cost data by transaction. These files can be maintained on bulk memory, dumped through the system printer, card punch, or magnetic tape, or reloaded for updates using manually entered corrected data.

Potential interchange transactions can be evaluated through two additional programs: Economy A Evaluation and Economy B Evaluation. These programs make use of two additional standard application programs: EDC Solution Routine and Dynamic Generation Scheduling Program.

The Economy A Evaluation Program is for use in evaluating the cost or savings associated with transactions to be implemented during the next few hours. This program combines the potential transaction with existing real-time system conditions to perform the evaluation. The EDC Solution Routine is used to determine the operating cost under the specified conditions. Minor changes in existing operating conditions can be made by alteration of the real-time base case data.

The Economy B Evaluation Program is designed for use in evaluating transactions for operating conditions that differ greatly from real-time conditions. This study may be in support of a future transaction, or may be for evaluation of a "dedicated unit" type transaction. This program utilizes the Unit Commitment program to determine the proper scheduling of units for use in the study. Operating costs for the transactions being studied are computed by the EDC Solution Routine as done with the Economy A Evaluation Program.

The results of these study programs are reviewed by the dispatcher, and the desired transactions can then be scheduled through the Interchange Transaction Scheduler.

5. <u>Interchange Transaction Scheduler</u>

The Interchange Transaction Scheduler (ITS) Program manages information regarding each scheduled transaction with non-associated interconnected companies or agencies. This information includes agency identification, type of interchange, associated costs and price quotations, magnitude and direction of the interchange, start time, ramp rate, and duration of the interchange transaction. Each scheduled transaction is assigned a ledger number for identification and filing in the transaction inventory. Based on this data, an inventory of interchange schedules is formed to store individual schedules in an organized manner. The schedule control processor computes the total net scheduled interchange for use by the Automatic Generation Control Program. It also provides interchange schedule data for the Transaction Accounting Monitor Program.

ITS consists of a number of processors and specialized data handling routines which service a central data base called the Inventory of Scheduled Transactions. It also provides an interface with other subsystems and other application programs.

An ITS Software Handler coordinates the execution of the various program processors, It determines the purpose of the program call and transfers control to the proper processors. The Initialization module is used only during system startup to initialize program functions. Depending on the source of the program call, the ITS Software Handler passes control to either the ITS Input Processor, the ITS Display Processor, or the Scheduling Coordinator.

Transaction schedules are made through the CRT operator's console, using the ITS Input Processor. Specialized routines are used to insert or delete individual schedules to/from the inventory. The ITS Output Processor provides display data for the operator's CRT. This allows operator entry of transaction pricing data as it is established. Each schedule is assigned a unique ledger number for filing within the inventory. Provisions are provided to store multiple transactions per agency. Each schedule entry is checked for legality, based on established scheduling rules. For example, the attempt to enter an Economy A Transaction with an agency currently scheduled to receive an Emergency Interchange, may result in an operator alarm.

A Scheduling Coordinator routine provides coordination of all schedules entered into the Transaction Inventory. It uses threaded list techniques to link schedules. The entered start and stop times for each transaction are used in the threading to determine the next schedule change to be performed. This routine schedules the ITS Program with the system executive using the "callback" technique to perform schedule changes at the required time. This routine also maintains the status of each transaction by flagging it as pending, active, completed or deleted. When schedule changes are required, the Scheduling Coordinator will pass control to the Schedule Control Processor. Completed schedules will be flagged to identify them for processing by the Transaction Energy Accounting Program. This program will construct historical files and generate reports giving energy and cost data on scheduled power exchange on a daily basis.

The Schedule Control Processor combines the scheduled transaction change with the current Interchange Scheduler and passes this value along with the transaction ramping rate to the AGC Program for implementation.

The Interchange Print Processor constructs schedule change messages for logging on the system's events or alarm printer.

These messages give the time, agency, type, and amount of each schedule transaction.

The Transaction Inventory contains all data related to an individual transaction, pending or completed. Start and stop times for schedules are specified by the year, day, hour, and minute to permit scheduling of future transactions. The total number of schedules in the inventory is limited by the storage provisions allowed for each agency. Data consistency checks are performed for each transaction entry and alarms are produced for error conditions. Also, the type of transaction (economy, emergency, payback, etc.) is also maintained in the inventory. Transactions may be scheduled up to one year in advance of the transaction. Price quotations by the utility and the transaction agency are also stored in the inventory. On an optional basis, reconstruction cost data computed by the Cost Reconstruction Monitor Program may also be entered into the inventory.

The Inventory of Scheduled Transactions may be accessed by the Transaction Accounting Monitor, the System Load Forecast Program, the Economy A Transaction Program, or other study type programs which require a future projected load value.

6. Transaction Accounting Monitor

The Transaction Accounting Monitor (TAM) collects data related to the cost accounting required for all interchange transactions. This data is maintained in coordinated historical files. It is also printed in a daily report for use in off-line billing procedures. Transaction accounting data is taken from the inventory of transactions maintained by the Interchange Transaction Scheduler Program. This data is also used to compute the inadvertent interchange data acquisition system. Files are maintained and updated for each hour of operation. Provisions are also made for entry of after-the-fact pricing data.

TAM is concerned with observation of two classes of data: interchange energy data and completed transaction data. This data is processed and accumulated into files for reports and off-line processing. The program is modular, consisting of a number of processors which construct these files and reports. The program is scheduled for execution after the hourly kWh data scan and Cost Reconstruction Monitor (if present) calculations have been completed.

The program's Interchange Energy Processor constructs hourly

files of scheduled and actual interconnected tie energy flow on a system-wide basis, and computes inadvertent interchange. Actual kWh energy flow for each tie line is obtained from the kWh scan data collected hourly by the data acquisition subsystem. The net schedule interchange is obtained from the Interchange Transaction Scheduler Program through the Transaction Inventory Files. This data is used to determine the inadvertent interchange accumulated during the hour. Provisions are made to determine on and off peak accumulation of inadvertent interchange over a 24-hour period. This data can be reported as required through events logging, accumulated in the bulk memory files, and reported on a daily basis. This data can also be displayed through a CRT Display for manual updates by the system dispatcher, based on manual readings or negotiated final transaction costs.

The tie line energy data file typically contains the following hourly data:

- KWh actual energy for interconnection tie lines
- Net interchange MWh accumulation for the hour
- Scheduled net interchange for the hour
- Inadvertent interchange for the hour
- Accumulated on and off peak inadvertent interchange for the day (up to the current hour)

These files are identified by the date on which they were created.

A Completed Transaction Processor interfaces with the Transaction Inventory to process transactions completed during the past hour. This processor computes the total scheduled MWh for each transaction. All data associated with a completed transaction is removed from the Transaction Inventory and that transaction's status is changed to indicate that the transaction is deleted. This procedure allows the Interchange Transaction Scheduler to utilize that file entry for a new future transaction.

The completed transaction file typically contains the following data for each transaction:

- Transaction Inventory ledger number
- Identification of non-associated interconnected agency

- Type of transaction
- Magnitude and direction of interchange
- Start time, date, year
- Stop time, date, year
- Utility price quotation, agency price quotation
- Reconstruction cost with and without each transaction (included only if the application requires the Cost Reconstruction Monitor Program)

These files are of fixed length and are identified by the date on which they were created.

An Historical File Builder takes the tie line energy data and the completed transaction data, and enters it into the daily transaction files maintained in bulk memory. Up to N(N is typically 4 to 7) daily files are maintained in bulk memory. This allows after-the-fact updates to the transaction and tie line data, by the system dispatcher, to accommodate agreements reached on pricing or adjustment to computed cost data. These storage provisions also accommodate weekends and holidays when final action on completed transactions may be deferred.

An Historical File Display and Update Processor allows for selective display on the CRT of tie line and transaction data stored in a particular daily file. This allows operator entry of updates or corrected data to these files. This is especially helpful for the cases already mentioned in relation to after-the-fact transaction pricing.

The TAM program is interfaced to the generalized system Information Storage and Retrieval Software, which allows for removal of daily files from bulk memory. This can be performed in a number of ways, such as printed reports, punched cards, or magnetic tape, as required by the application. This is usually influenced by the analysis, accounting, or billing procedures which utilize these files. The actual method used is dependent upon the overall operating procedures required for a particular application.

7. <u>Transaction Reconstruction Monitor</u>

The Transaction Reconstruction Monitor (TRM) collects data related to the cost or savings associated with active interchange transactions. This data is used to evaluate the effectiveness of prenegotiated economy transactions, to determine the cost efficiency of transactions, and for after-the-fact price determination

of completed transactions (Economy A, for example). Savings are estimated through the use of the EDC Solution Routine calculation. The scheduled net interchange is modified for each transaction in turn,to represent its effect on system load. Scheduled transactions are removed, based on a priority sequence established by the utility's operating policy. Results of the reconstruction calculations are structured into hourly files in bulk memory.

Provisions are made to manually update these files and to dump them for off-line processing.

TRM is one of the optional programs in the Transaction Management Package. It interacts with the inventory of scheduled transactions maintained by the Interchange Transaction Scheduler. It stores average production cost data into that file for later processing by the Transaction Accounting Monitor.

TRM produces two classes of data. One is the average production cost data,which is calculated during the hour for each active transaction. This data is stored into the transaction inventory. The other class of data consists of hourly production cost data for individual units and transactions. These files are constructed by TRM and maintained in bulk memory. This data can be dumped under operator direction for off-line processing. The program is executed periodically (typically every 5-10 minutes) and updates the historical transaction cost files at the end of each hour.

TRM is made up of functional modules, each designed to perform one step in the reconstruction calculation and management of the resulting historical files. The first step in the reconstruction cost calculation consists of establishing the base case data for the Economic Dispatch Calculation. This is done by an EDC Base Case Preprocessor. Real-time data from the system data base, consisting of unit status and generation data, is captured and placed in the base case files. This procedure is also followed for the current parameters (fuel cost, incremental heat rates, loss data) used by the real-time EDC. By transferring this data into a study data base, the effects of real-time data gathering and data entries are blocked from affecting the reconstruction calculations.

The next module in the execution of the program is the Reconstruction Sequence Logic which interrogates the ITS Transaction Inventory to obtain data which identifies all currently active transactions. A priority is assigned to each active transaction based on its type, duration, etc., as dictated by utility operating practice. This priority determined the sequence in which schedules are removed from the system in computing reconstruction cost. An example of this sequence would be to remove all emergency transactions followed by all Economy A transactions. Transactions of the same type may be ranked on the basis of the sequence in which they were negotiated.

Reconstruction calculations are controlled by the Reconstruction Loop Module, which removes each transaction in turn. This is done by reducing total system load to be dispatched by the amount of the transaction under evaluation. Each time the scheduled net interchange is changed, tie line distribution factors are used to determine the associated flow on the system tie lines. The resulting data, along with the Base Case File Data established earlier, is then used in the EDC Solution Routine. The resulting desired generation values are used to compute corresponding production costs for each generation source, and for the system as a whole. The resulting data is stored in an Inter-Hour Production Cost Data File. This calculation sequence is repeated for each currently active interchange transaction.

The Hourly Averaging Routine is scheduled for execution at the end of each hour. This routine takes data from the Inter-Hour Production Cost Data File, and calculates average production cost for the hour, for each active or currently active transaction. The resulting data is stored with other transaction data in the Transaction Inventory. For ongoing transactions, each hour's average production cost is combined with the duration of the transaction expressed in hours.

Another routine that is scheduled for execution at the end of each hour, is the Historical File Builder. This module constructs files containing detailed cost data for each active transaction for each hour it is active. These files are constructed for each day and are identified by the transaction ledger number.

The files typically contain the following data for each transaction for each hour it is active:

- Hour of the day
- Transaction Inventory ledger number
- Identification of non-associated interconnection agency
- Type of transaction
- Incremental production cost of each generation source
- Incremental maintenance cost of each generation source
- Incremental system losses resulting from the transaction

Up to N (N is typically 4 to 7) daily files are maintained in bulk memory. This allows after-the-fact updates to the transaction production cost data, by the system dispatcher, to accommodate changes in the real-time system. These storage provisions also accommodate weekends and holidays, when final action on completed daily files may be deferred.

An Historical File Display and Update Processor allows for selective display on the CRT Console of reconstruction data stored in a particular daily file. Updates to these files may be made through these displays.

This program is interfaced to the generalized system Information Storage and Retrieval Software, which allows for removal of these files from bulk memory. This can be performed in a number of ways, such as printed reports, punched cards, or magnetic tape, as required by the application. This is usually dependent on the analysis, accounting or billing procedures which utilize these files. The actual method used is dependent upon the overall operating procedures required by a particular application.

8. <u>Economy A Transaction Evaluation</u>

This program performs a production cost evaluation to establish the cost or savings resulting from an economy energy transaction with a neighboring agency. Economy A Transactions are typically made on a short-term basis based on committed units, and utilizing spinning reserve. They are cancellable either by transaction agency, or renewed on an hour-by-hour basis. Typically, pricing is established on a split-the-savings basis. This program is one of the optional programs in the design coordinated Transaction Management Package.

The evaluation is initiated by the system dispatcher on a demand basis. A CRT Display is used to enter the hour to be studied, the estimated system load, planned changes in unit commitment, the transaction amount, and the increments to be studied. Each transaction increment results in a full pass through the calculations. Initially, a base case calculation is performed to establish base operating cost for expected system load and previously scheduled transactions.

The basis of the Economy A Transaction Evaluation (ITAE) is the EDC Solution Routine, separate from, but similar to the real-time economic dispatch. This includes a Full B-Matrix Loss Calculation and a Desired Generation Calculation. The resulting desired generation values are then used to calculate production costs and other Economy A calculations. Based on the results of the evaluation, acceptable schedule data can be directly entered into the Interchange Transaction Scheduler Program.

ITAE consists of a number of processors and specialized data handling routines which create and process a number of study data files. To initiate an Economy A Study, the following data is entered through a CRT Display:

- Agency being studied
- Hour of the study
- Expected system load
- Power exchange to be evaluated
- Transaction increments to be studied
- Changes in status of units on-line
- Tie line distribution factors to be used

A Base Case Processor is used to retrieve other system data required for the execution of the economic dispatch calculation. This data is structured into the Base Case Data File to insure immunity from the system changes during the study calculations. This data includes:

- Unit operating status modified by operator entries
- Unit operating limits
- Unit fuel costs
- Unit incremental heat rate data
- Unit incremental maintenance data
- Transmission loss constants
- Non-conforming load data

The scheduled net interchange that exists during the hour studied is obtained from the Transaction Inventory maintained by the Interchange Transaction Scheduler.

A Study Pass Processor controls each pass or execution of the program for the increments of the interchange under evaluation. The initial execution path computes production costs without any additional interchange to establish base case values to be used as a reference. Then, each increment of the transaction under evaluation is added to existing net interchange and another pass is made. Before each pass the net interchange scheduled is divided among the interconnection tie line through predetermined tie line distribution factors. These factors assign the portion of the net interchange each tie line can be expected to carry under actual operating conditions. Alternate sets of these factors may be used to better match operating conditions that will be known to exist, for the time being studied. These alternate factors will be specified as part of the study definition. This allows a distinction to be made between on-peak and off-peak operation or weekday versus weekend or holiday.

The basis of the Economy A Evaluation is the EDC Solution Routine. At the conclusion of the EDC the Economy A Calculation is executed. This module computes the production cost data based on the desired generations computed by the EDC. These calculations include the total system cost, average cost for the transaction increment under study, and the weighted average cost for the agency being studied. All results are stored in the Study Results File.

A CRT Display of pertinent results is formulated to allow the operator to evaluate the study results. Based on the data displayed, the dispatcher can negotiate a transaction and enter the additional transaction data required. This data can be directly passed to the Interchange Transaction Scheduler. Alternately, the dispatcher can select a full study report to be printed on the system printer. Based on this report, the dispatcher can then enter the new schedule by the standard procedures provided by the Interchange Transaction Scheduler.

9. <u>Economy B Transaction Evaluation</u>

This program performs a production cost evaluation to establish the costs or savings resulting from an economy energy transaction with a neighboring agency, based on possible operating conditions. Economy B transactions are typically made well in advance of implementation and require commitment of additional generation resources. Pricing is typically established on the basis of the anticipated operating conditions and may include startup cost of additional generating sources. This program is one of the optional programs in the design-coordinated Transaction Management Package.

The basis of the Economy B Transaction Evaluation (ITEB) is the Rockwell Dynamic Generation Scheduling (DGS) program. The implementation of this program requires implementation of the DGS program. ITEB provides a convenient means for coordinating the use of DGS for this type of study function. The DGS is unaffected by its use in an Economy B Transaction Evaluation.

The evaluation is initiated by the system dispatcher on a demand basis using a single Economy B Transaction Evaluation display. The program is a study type and supports a number of study cases. Each study case supports a single evaluation and may be maintained by the system until it is reused for a new evaluation. To start the study, the dispatcher selects an available study case and enters the transaction MW increment to be studied along with the date, hour, and duration which serves as the study case identification. The program then requests execution of the DGS program. The dispatcher can use the DGS program input displays to further establish input data prior to initiating execution to perform the Economy B Transaction Evaluation.

Following the first pass execution of the DGS program, control is returned to the Economy B Transaction Evaluation program along with the identification of the DGS Study Case which was used. The final hourly production costs data is captured from the DGS Study Case to the ITEB Study Case. ITEB then modifies the DGS Study Case to include the effect of the additional interchange to be evaluated using the "Previous Case" input option and requests a reexecution of the DGS program.

Following this second pass of the generation scheduling study, control is again returned to ITEB. Again the hourly production costs are captured into the ITEB Study Case. The production cost figures are then compared and summarized on the ITEB Study Case display for review by the dispatcher. Typically, one study increment is used for a study of this type. The dispatcher can use the resulting hourly production cost data to approximate the added cost of interchange increments of varying sizes. Alternately, he may also request the DGS program directly, call up the second pass version of the DGS Study Case, and make further alterations and study reruns directly.

10. Adaptive Load Forecast Study

The Adaptive Load Forecast program uses a generalized load-weather model and forecasted weather conditions to forecast hour load for the next 24-30 hours of operation. The generalized load model consists of components representing the base load, the day of the week load, the weather induced load, the scheduled non-conforming load, and the random load. Multiple load models can be defined for each distinct load center or region, each having distinct load or weather characteristics. These models would be custom fit to the user's service area based on an engineering analysis of previous weather and load data. The methodolgy makes use of stepwise linear regression techniques. The program maintains load-weather models on-line, and dynamically adapts these models to seasonal changes in weather and load. This adaptive procedure recognizes the load growth trend, the daily load profile, and the weather-induced load effect.

In application, the base regional load component and the day-of-the-week component are modeled jointly. This is accomplished by forming separate hourly models for each day of the week, thus eliminating the need to separately model each component and then combining the results. The base load models use exponential smoothing techniques.

The weather induced component of the load is modeled by a summer model and a winter model, each containing appropriately selected weather variables. While the program is somewhat generalized in its processing of the load components and load-weather models listed above, it must be tailored to the user's service area through a study of historical data. This analysis will be performed during implementation based on actual utility load and weather data.

The scheduled non-conforming load requires no modeling. Table look-up procedures are used to add into the load model known and prescheduled non-conforming loads. Likewise, the random load component cannot be modeled since it represents the truly random portion of the load which cannot be forecasted. It can also be viewed as forecasting error.

Selection of proper weather variables is a key part of this load-weather modeling. For a summer model, temperature has always been a key load-related variable due to cooling load. Cooling demand is related to dry bulb temperature minus a constant reference temperature in the order of 60 to 65 degrees F. In a summer model, cooling demand may also be related to the difference in moisture content of the air before and after dehumidification. In the summer many buildings are open to the outside and inside temperature tracks ambient directly up to a certain point where heat buildup becomes a factor. Similarly, for winter models the heating load is related to a constant threshold, minus dry bulb temperature. And while moisture content of the air has less influence in the winter model, wind velocity may greatly affect load at lower temperatures. Because buildings tend to be closed up during the winter, lagged weather variables may be required to model the thermal time constants or heat storage effects of buildings.

Many of these relationships are complex, and if mathematically well-behaved linear regression techniques are to be used, suitable weather variable transformations must be determined. This determination is made from an analysis of historical weather and load records.

Three programs are used to perform the system load forecasting function: Load Forecast Model Update, Forecasted Weather Data, and System Load Forecast. These on-line programs are supported by a file created by the batch mode Load-Weather Parameter File Program.

The basis for the load forecast procedure is the Daily Operations File and the Load-Weather Parameter File. The Daily Operations File contains the load and weather data. This data supports the important off-line procedure of model initialization through the Load-Weather Parameter File program. This program uses approximately two months of data to initialize the parameters of the model determined by manual analysis, as described previously. The program allows restarting of the forecasting model

initially (system startup) and whenever required by non-availability of weather and load data, or the use of erroneous data (transducer failure, operator entry error, etc.). This program would be used infrequently and is not part of the daily load forecast processing. The resulting Load-Weather Parameter File is the basic "memory" required for the forecasting procedure and contains the current parameters of the various load models.

The Load Forecast Model Update Program provides the important adaptive capability of the forecasting procedure. It continuously adapts the model in real-time by tracking load growth, seasonal effects, and weather patterns. The rate at which the adaptation takes place is matched to the dynamics of the associated load component. This eliminates the need for any on-line program tuning. The update programs execute daily at midnight to process the previous day's load and weather data, as recorded in the Daily Operations File. It can also be executed on demand to process data that may have been entered manually to correct erroneous data. The resulting model update data is stored in the Load-Weather Parameter File.

The Forecasted Weather Data Program processes system operator entered data on demand for use in forecasting. The entries include forecast day, scheduled non-conforming loads, and forecasted weather variables. This data is combined with any actual weather data available from the Daily Operations File for a same day forecast. Weather data may be entered through the System Load Forecast Request Display at three-hour intervals, to match availability from the U.S. Weather Bureau stations. Missing or non-entered data can be approximated using profiles from previous weather variable patterns. Once processed, a complete set of forecasted weather data is stored in the Forecasted Weather Data File. These daily files can be recalled to the System Load Forecast Request display for entry of additional data as required.

The System Load Forecast Program executes on demand through entries made by the system operator. This program retrieves the current model data from the Load-Weather Parameter File and reads the processed weather data sent from the Forecasted Weather Data File for the day to be forecasted. System calendar data is used to identify known holidays in order to substitute the appropriate load-weather model. The resulting hourly forecast for the region is stored by date, in the System Load Forecast File

and displayed through the System Load Forecast display.

11. State Estimation

The State Estimator (STATEST) estimates the Bus Injection vector making use of the various real-time measurements for the purpose of system load flow and real-time contingency analysis. It also makes bad-data checks for any possible errors in instrumentation or communication. STATEST is typically dimensioned to process the same network used by the On-Line Load Flow programs, and is coordinated in design with that package so it may be added at any time. This package is capable of independent execution due to the inherent stability of the solution techniques and the use of averaged input data.

State Estimation is superior to all other methods for calculating the bus injection vector of the internal power system. This injection vector would then be available for running a System Load Flow. The most frequent need for a System Load Flow would be for establishing the base case for Contingency Analysis. On this basis, State Estimation would be executed at the same time period as that program. This frequency of execution would be satisfactory for the bad-data identification function.

The State Estimator module will use the following types of measurements:

- Line Flows, P and Q
- Line Currents
- Bus Injections, P and Q
- Bus Voltages

Psuedo-measurements will be used wherever possible, such as zero P and zero Q bus injections at all the passive nodes of the network.

The State Estimation methodology is based on the full use of the available measurement set. The algorithm used is the method of measurement transformation. There are currently three other alternative methods: AEP, basic weighted least squares (WLS), and sequential modified Kalman filter. The AEP method uses line flows only and ignores the availability of other measurements. The WLS and the sequential method both use the full measurement set, but are based on a linearized model of the measurement set. In particular, using the WLS approach entails recalculation of large matrices.

The Transformation method applied by STATEST transforms the measured quantities into variables which are linearly related to the system state. This results in a constant gain matrix which can be precalculated. This feature makes the Transformation method more effective for on-line use than the basic WLS. The Kalman filter method has not yet been proven to work efficiently for large systems.

The method used by the State Estimator is the Transformation method introduced by Johnsson. Given the measurement set Z, a non-linear transformation g is applied such that:

$$Z'=g(Z,X)$$

where X is the state vector.

The structional transformation g is chosen such that Z' is linear in X. Hence,

$$Z'=HX + v$$

where H is a constant matrix and v is Gaussian zero-mean error. The standard weighted least squares approach is applied to the transformed measurement set Z'.

The convergence characteristics and accuracy of the State Estimator will depend to a large extent on the accuracy of the network model that is supplied by the user, and the measurement system meter configuration that is available. The network model must be connected, and complete with valid impedance and admittance values. For example, power industry experience has indicated that the reactive power flow estimates are very sensitive to inaccuracies in line-charging susceptance. Redundancy in measurements will tend to reduce the estimation errors caused by inaccurate parameters, but this will be strongly dependent upon the number and location of the measurements. The measurement configuration should be based on the reliability and accuracy of the measured values and resulting accuracy of the state estimation.

12. System Status Processor

The System Status Processor (SSP), which consists of three modules, maintains the operational in or out of service status and network connectivity of the following power system equipment based on the status of the breakers and disconnects acquired through the data acquisition software:

- Nodes, i.e., bus bars and measured load buses
- Lines
- Transformers
- Generators
- Capacitor Banks
- Interchange Tie Lines

The resulting information is used to update the logical and mathematical representation of the power system for use by the On-Line Load Flow Program and by the man-machine display software.

The first of these modules compares the current switching device status against predefined switching device configurations to detect equipment status changes. In this context, switching devices means breakers or disconnect switches, while the term equipment is used to indicate one of the above types of power system equipment. In general, the status of equipment is determined by the status of several switching devices within the station configuration. This predefined switching device configuration is established in tables when the data base is generated. For instance, a transformer within a station may be out of service if any of several conditions occur, such as the tripping of several breakers, the outage of all lines feeding the station, or a combination of line outage and breaker trips. The switching device configuration is conveyed to the software in terms of a cross-reference list, that relates all possible connections of equipment to the switching devices.

The second module is used to time out outages and returns-to-normal for equipment. When the equipment outages are detected by the first module, an entry is made in a queue, where it remains until a prespecified time interval is exceeded. The second module maintains the queue and associated tables for this purpose.

The third module is used to process changes to line-oriented status tables to reflect current operating conditions. The module serves as a single source update program for the system line and transformer status tables. Besides performing status change requests for the previous module, the third module processes newly alarmed transformers and transmission line overloads and line overload returns detected by the data acquisition software.

13. On-Line Load Flow Program

The Load Flow Study Program provides the user with a comprehensive capability to analyze his system's behavior for a variety of current and anticipated operating conditions. The program operates on-line using the console CRT's for efficient interaction between the dispatcher and the load flow model. Complete control over all data used in the analysis is established through a series of CRT data displays. The analysis may be initiated by a multiple number of operating cases, established current conditions, base case conditions, or previously established operating cases, to insure fast setup. The analysis of the load flow model may be performed using the Fast Decoupled Load Flow Algorithm to provide efficient and reliable on-line execution. Results are provided in summary form through CRT displays or in detail from using printed reports.

The methodology used by the program is the Fast Decoupled Load Flow. This is a full A-C load flow, not an approximate one, with the same accuracy as the well-known Newton-Raphson method, but with at least three times the computational speed, less storage, and more reliable convergence characteristics. Currently, the Fast Decoupled Load Flow is the most efficient load flow method available and is the most suited for control center application where speed and concern for storage are prime considerations.

The Fast Decoupled Load Flow Algorithm decouples the real power and reactive power equation as follows:

$$\frac{\Delta P}{V} = B' \, \Delta\theta$$

$$\frac{\Delta Q}{V} = B'' \Delta V$$

where:

ΔP = the mismatch vector (scheduled net real injection - calculated real injection)
ΔQ = the mismatch vector (scheduled net reactive injection - calculated reactive injection)
B' = the (-B)terms of Y-bus matrix (G + jB) omitting shunt reactances and off-nominal in-phase transformer taps
B'' = the (-B) terms of Y-bus matrix (G + jB) omitting the angle shifting effects of phase shifters
$\Delta\theta$ = phase angle correction to be solved for
ΔV = voltage magnitude correction to be solved for

The constant matrices B' and B" are triangularized only once,at the beginning of each process.

The program achieves its flexibilty, efficiency, and interactive capability through modularity and centralized data organization. The program consists of a supervisor, a set of optional interim study processors, a solution routine, and a results processor. These processors establish a unique set of data files referred to as "Operator Cases" for each load flow study. The Operator Case contains all data associated with the study including raw input data as well as intermediate results. In this regard, the Operating Case serves the same functions as a conventional load flow's base case. A multiple number of Operating Cases are supported by the program.

Program control is established by the Load Flow Study Supervisor through the Load Flow Study Control display. This display allows the operator to initiate a study to either current operating conditions taken from real-time data base, a stored base case, or a previously established operating case taken from the load flow study files stored in bulk memory. The Supervisor copies the appropriately selected data into the initialization data table area of the active operating case.

Then, at the discretion of the operator, the Supervisor schedules for execution,one or more of the interim study processors to condition data for use in the load flow study. Each of these processors is interactive,using functional data display to allow the operator to enter and review data in a format familiar to him. For example, line and bus data are entered through substation level displays similar to those used to support the real-time

system. Only data changes required for a particular analysis need be made. These processors then construct the interim study results tables to complete the data preparation required for definition of the system model.

The assembled data is then analyzed by the Load Flow Solution Routines on either a primary or secondary computer and the results are stored in the currently active Operating Case. Results may be reviewed through CRT displays in summary form or through detailed sub-station level displays. A separate Load Flow Results Processor is provided to print a detailed report of the load flow study results.

One remarkable feature of the Fast Decoupled Load Flow Algorithm is that it can be used for both full AC, and approximate AC Contingency Analysis. For approximate solutions the algorithm would be executed with just one phase angle iteration. A number of contingency conditions could be checked on an approximate basis, while selected contingencies could be solved through a full AC Load Flow.

14. Other Programs

The following is a listing of other application programs that are not described herein but which may be of interest to the borrower:

- Dynamic Generation Scheduling Study
- Real-Time Contingency Check Monitor
- Remedial Action Determination Study
- Radial Load Bus Voltage Control
- On-Line Loss Matrix Program
- Off-Line Power Flow Program
- Interchange Billing
- Energy Accounting
- Work Order Scheduling
- Post Disturbance Analysis
- Security Analysis
- Contingency Remedial Action
- Bus Load Forecasting
- Unit Commitment
- Power Flow

APPENDIX B

GLOSSARY

GLOSSARY

ACE - Area Control Error - The area net interchange minus the biased scheduled area net interchange. This signal is used by the AGC programs to meet the G&T's regulating responsibility.

ADC - Analog-to-Digital Converter - A device that converts a signal that is a continuous function of a variable, into a representative number sequence.

AGC - Automatic Generation Control - The regulation of the power output of electric generators within a prescribed area in response to changes in system frequency, tie line loading, or the relation of these to each other, so as to maintain the scheduled system frequency and/or the established interchange with other areas within predetermined limits.

ASCII - USA Standard Code for Information Interchange.

Auxiliary Memory or AUX MEM - A rapid access device used for the on-line storage of logic and data.

Bulk Delivery Line Tap - A small delivery point with a single controllable breaker or motor-operated switch.

Bulk Delivery Substation - A delivery point with dual feeds, transformation and multiple outputs. Contains several controllable devices including breakers, switches, and load tap changers.

CONTROL - Controller - The electronic interface between the CPU's IOP and a peripheral device.

CPU - Central Processing Unit - The unit of a computing system that includes the circuits controlling the interpretation and execution of the instructions.

CRT - Cathode Ray Tube - An electron beam tube in which the beam can be focused to a small cross section on a luminescent screen and varied in position and intensity to produce a visible pattern. The primary man/machine interface device in the system.

Cursor - A special CRT character used for marking specific positions on the face of the tube, thereby allowing the System Dispatcher to communicate selection of a particular CRT representation for BPU action.

Delivery Point	-	Any point in the power system of which power is received and metered from the interconnected utilities. Can be any of three configurations. Meter Point, Bulk Delivery Line Tap, or Bulk Delivery Substation.
DS	-	Data Set - A device used to interface the control system to the communications channels, by modulating-demodulating digital signals into audio tone.
DSC	-	Data Set Controller - A device connected to the IOP that controls the operation of the data set.
DS/C	-	Data Set/Controller - The combination of a data set and its associated data set controller.
ECS	-	Energy Control System.
EDC	-	Economic Dispatch Calculation - The distribution of total generation requirements among alternate sources, to optimize system economy with due consideration of both incremental generating costs and incremental transmission losses.
Function Panel	-	A grouping of pushbuttons used to communicate specific System Dispatcher commands to the CPU.
Hardware	-	The mechanical, magnetic, electrical and electronic devices incorporated into the system.
IEEE	-	Institute of Electrical and Electronics Engineers.
I/O	-	Input/Output - Pertaining to all hardware and activity that transfers information into or out of a computer.
Keyboard	-	A device used in conjunction with the CRT for alphanumeric data entry.
KSR	-	Keyboard-Send-Receive Unit - A typewriter-like device used by the programmer to communicate with the software operating system.
Load Flow	-	A calculation that provides power flows and voltages for a specified power system, subject to the regulating capability of generators, condensers, and tap-changing-under-load transformers, as well as specified net interchange between individual operating systems.

Logger - A medium speed printing device used to record alarms, logs and other pertinent operating information.

LTC - Load Tap Changer.

Meter Point - A small delivery point with no controllable breakers or switches.

NAPSIC - North American Power System Interconnection Committee.

Off-Line - Pertaining to equipment, devices and programs not under direct control of and interacting with the real-time control system.

On-Line - Pertaining to equipment, devices and programs under direct control of and interacting with the real-time control system.

Participation Factor - A factor which is used to allocate generation changes to a unit. Separate factors are provided to allocate short term (regulation) and longer term (economic) changes in generation.

Penalty Factor - A factor which, when multiplied by the incremental cost of power at a particular source, produces the incremental cost of delivered power from that source.

Poll - To send a command to a piece of hardware requesting that specified stored data be transmitted, processing the received data point-by-point in logical sequence, and storing the data for future use.

Printer - A high speed hard copy device used to document programs and lengthy reports of operating information.

Quality Coding - A label or other designation indicating the source and/or reliability of data.

Real-Time - Pertaining to the performance of a computation, during the actual time that the related physical process transpired, in order that the results of the computation can be used in guiding the physical process.

RTU - Remote Terminal Unit - That part of the system that includes all supervisory control relays and associated devices located at the remote station for selection, control, indication, telemetering and other functions to be performed.

SCADA - Supervisory Control and Data Acquisition.

Scan - To send a command to a piece of hardware requesting that specified sensors be connected to measuring equipment and a digital count value, or a binary digit, be generated and transmitted, processing the received data point-by-point in logical sequence, and storing the generated data for future use.

Software - Programs or routines which instruct the operations of a computer(s) and the supporting documentation which describes them.

System Dispatcher - The person or persons duly authorized to operate digital monitoring or dispatch equipment.

UPS - Uninterruptible Power Supply - Equipment used to supply power to critical loads even when the normal power supply fails.

APPENDIX C

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BIBLIOGRAPHY

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Appendix D

PRICING WORK SHEETS

PRICING WORK SHEETS

Name of Bidder____

1. Total System Firm Price $____________________

   Including all hardware, software, installation, integration, test, test equipment, documentation, warranty, insurance and opportunances. Taxes not to be included.

2. Insurance Provisions

   Has your bid taken into account the insurance provisions of Section 9, Article IV, Section 3. (Answer yes or no) ____________________

3. Conformity with Bid Documents

   Bidder hereby certifies that he agrees to all provisions of the specification and bid documents, unless exceptions are specifically and clearly listed in the proposal and identified as Exceptions. Bidders printed terms and conditions are not considered specific exceptions. Any exceptions which Bidder has taken are listed on: Page(s)________________

4. Major Subsystem Price Details

   The Bidder shall submit subsystem pricing as set forth below:

   4.1 Total price of computer system and peripherals $____________________

   4.2 Total price of communication subsystem including computer interface hardware $____________________

4.3 Total price of consoles including CRT's, display generators and computer interfaces $________________

4.4 Total price of wallboard assembly less internally mounted components $________________

4.5 Total price of RTU's $________________

4.6 Total price of local RTU or equivalent device $________________

4.7 Total price of analog ACE calculator $________________

4.8 Total price of video hardcopy printer including necessary interfaces $________________

4.9 Price of RTU test sets (total) $________________

4.10 Price of all other hardware $________________

4.11 Total hardware price $________________

4.12 Price of all application programs $________________

4.13 Price of the operating system(s) $________________

4.14 Price of all programmer's aids $________________

4.15 Price of all utility software $________________

4.16 Price of all system software (communications, special handlers, man-machine, etc.) $________________

4.17 Price of software other than above $________________

4.18 Total software price $________________

5. Engineering, Installation and Management Prices

5.1 Total man-hours and price including expenses allocated for all field and factory support activities subsequent to factory shipping ________________ $________________

5.2 Program management and system engineering $________________

6. Miscellaneous Prices

6.1 Documentation $__________

6.2 Shipping $__________

6.3 Insurance $__________

6.4 Initial delivered expendables $__________

6.5 Warranty $__________

6.6 Contractor's bond $__________

7. All other costs not included in Items 4 through 6. The sum of Items 4 through 7 should equal the value entered in Item 1 $__________

8. Optional Item Prices

8.1 Firm price for initial spare parts $__________

8.2 Training program $__________

8.3 One-line diagrams and associated tabular displays $__________

8.4 Supplier provided maintenance plan $__________

8.5 (a)Security monitoring implementation if provided with initial system. (Include hardware and software) (b)Same as Item (a) but provided after system acceptance $__________ $__________

8.6 Dual Port Interface $__________

8.7 Sequence of events capability per applicable RTU's only $__________

9. Post Acceptance Support

Provide daily rate costs including per diem for:

9.1 System analysts $__________

9.2 Other software personnel $______________

9.3 System hardware maintenance personnel $______________

10. Incremental Prices

The Bidder is requested to provide incremental prices for the following:

10.1 Average RTU prices

a) Small $______________

b) Medium $______________

c) Large $______________

10.2 RTU Points

a) Discrete inputs with memory in groups of: $______________

b) Discrete input w/o memory in groups of: $______________

c) Analog points in groups of: $______________

____

d) kWh accumulator points in groups of: $______________

____

e) Analog set points in groups of: $______________

____

f) Pulse drivers in groups of: $______________

____

10.3 Additional CPU Memory

a) Increment (k words) ______________

b) First additional increment $______________

c) Subsequent increments $______________

10.4 Disk

a) Additional disk packs for (k bytes) $____________________

b) Additional disk drives including controller if required $____________________

10.5 Console shell price per bay $____________________

10.6 Selected applications

a) AGC/ED $____________________

b) Interchange transaction scheduling $____________________

c) Load forecasting $____________________

d) Unit commitment $____________________

e) Interchange transaction evaluation $____________________

f) Production costing $____________________

g) After-the-fact interchange billing $____________________

APPENDIX E

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International System of Units

In December 1975, Congress passed the "Metric Conversion Act of 1975." This Act declares it to be the policy of the United States to plan and coordinate the use of the metric system.

The metric system, designated as the International System of Units (SI), is presently used by most countries of the world. The system is a modern version of the meter, kilogram, second, ampere (MKSA) system which has been in use for years in various parts of the world.

To promote greater familiarization of the metric system in anticipation of the U.S. converting to the system, REA is including metric units in its publications. This bulletin has, therefore, been prepared with the International System of Units (SI) obtained from ANSI Z 210-1976 - Metric Practice. Approximately equivalent Customary Units are also included to permit ease in reading and usage, and to provide a comparison between the two systems.